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Structural Changes of Hot Rotating Neutron Deficient Doubly Magic Nucleus ^{100}sn

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***Abstract* - This paper presents results of statistical calculations of single-particle characteristics of nuclei, excitation energies and shape transition in the Sn isotope with neutron number 50, which is the extremely neutron deficient isotope. It is a very rare and unstable isotope which does not occur in nature, but only on the surface of exploding stars for less than a second. The spherical nucleus at its ground state is more stable in its shape against temperature and angular momentum. The decrease in proton separation energy with increasing spin around E_x = 14MeV at spin J ≈ 30ħ may be due to the transition from S_n to I_n through the transformation of a single proton in ^{100}Sn to a neutron via the nuclear process of decay.**
***Keywords:* Doubly magic nucleus, level density; separation energy; nucleon emission; shape transition**

I. INTRODUCTION

A number of experimental and theoretical studies are currently focused on nuclear structure evolution far from the line of stability. The shell structure of atomic nuclei is associated with 'magic numbers' and originates in the nearly independent motion of neutrons and protons in a mean potential generated by all nucleons. ^{100}Sn is a very rare and unstable isotope of Tin, which does not occur in nature, but only on the surface of exploding stars, and that too for no more than a second. In particular, the structure of neutron-deficient nuclei near the N=Z line is impacted by protons and neutrons occupying the same shell model orbitals and thus the spatial wave functions are identical. Probably ^{100}Sn is the heaviest doubly magic nucleus with equal numbers of protons and neutrons. Though the formation of ^{100}Sn is very difficult, Hinke et al.[1] have produced it in a projectile fragmentation reaction of a ^{124}Xe primary beam impinging on a Beryllium target with an energy of 1GeV, and obtained the half life of $T_{1/2}$ = 1.16 ± 0.20s. Guastalla et al.[2] discussed the evolution of nuclear structure of ^{100}Sn and the result was reproduced by shell model predictions which indicates a shell closure at *N*=*Z*=50. Isakov[3] studied the neutron deficient ^{100}Sn to neutron excess ^{132}Sn isotopes extensively in the HF+BCS approach and compared with experimental data, available at present.

The investigation of the nuclear structure of doubly magic nuclei and their neighbouring nuclei is of great interest since they are an ideal testing ground for nuclear structure models because the modeling of these systems can be reduced to the coupling of a few particle- or hole-states to the closed core. The detailed study of the internal structure of this most exotic nucleus ^{100}Sn gives new and unique insights into the internal structure of atomic nuclei and the creation of elements heavier than iron. The doubly magic nucleus $^{100}Sn_{50}$ is most probably the heaviest N=Z nucleus which is stable against the emission of protons and alpha particles [4]. The doubly magic character of ^{100}Sn manifests itself by the large energy gap of approximately 6 MeV to the next shell for protons and neutrons which is caused exclusively by the spin-orbit interaction of the $g_{9/2}$ and the $g_{7/2}$ orbitals. Deana et al. [5] studied nuclei near ^{100}Sn using the ^{58}Ni+^{50}Cr reaction. It is quite interesting to note that the level schemes of ^{99}Cd and ^{101}In closely mirror those of the analogs in the ^{56}Ni region, ie., ^{55}Fe and ^{57}Co, and also, the lowest-lying core-excited states have almost identical excitation energies. This observation of closely related excitation energies in the 2+ state of ^{56}Ni and ^{100}Sn with almost similar shell gaps at Z=28 and Z=50 point out the large similarity between the two heaviest self-conjugated doubly magic nuclei[5]. In the ^{100}Sn region the Gamow-Teller decay is the only allowed decay channel and there is also the possibility of beta-delayed proton emission. With increasing distance from the valley of stability towards the proton drip line the proton separation energies decrease and Q-values of the beta-decay increase. The conversion of a $g_{9/2}$ proton into a $g_{7/2}$ neutron may populate final states in the daughter nucleus which are situated several MeV above the proton separation energy[1]. Their experiments confirmed the ^{100}Sn has the fastest beta decay of all atomic nuclei, as previously predicted by theoretical physicists. Currently many data on the the chain of Sn isotopes has been available and which is an important testing ground for nuclear theory since N=Z=50 lies almost middle of the nuclear chart [6-11]. At this juncture, it is highly interesting to know the structural effects of ^{100}Sn, against temperature and angular momentum, ie., hot rotating ^{100}Sn. In this work, statistical theory is followed to study the structural changes of this hot rotating nucleus.

II. THEORETICAL FORMALISM

The statistical quantities like excitation energy, level density parameter and nuclear level density which play important roles in the nuclear structure and nuclear reactions, are being calculated theoretically by means of the Statistical or Partition function method. In this work the statistical model approach is followed to probe the dynamical properties of the nucleus in the microscopic level. The entropy of the system is given by,

$$S = S_Z + S_N \qquad (1)$$

where, $$S_{Z(N)} = -\Sigma_i \left[n_i^{Z(N)} l_n\, n_i^{Z(N)} + \left(1 - n_i^{Z(N)}\right) l_n \left(1 - n_i^{Z(N)}\right)\right] \qquad (2)$$

where, the $n_i^{Z(N)}$ is the average occupation probability for proton (neutron).

The total excitation energy is obtained using

$$E^* = U(M,T) = U_{eff}(T) + E_{rot}(M) \qquad (3)$$

The single particle level density parameter a(M,T) as a function of angular momentum and temperature is extracted using the equation

$$a(M,T) = \frac{S^2(M,T)}{4U(M,T)} \qquad (4)$$

where S is the entropy and U is the total excitation energy. The neutron or proton separation energy is obtained from [12],

$$S_{n(p)} = \frac{TN(Z)}{E_i\left[\left(1 - n_i^{Z(N)}\right) n_i^{Z(N)}\right]} \qquad (5)$$

where N(Z) is the number of neutrons (protons). The dependence of the nuclear level density, ρ, on angular momentum M, can be written as

$$\rho(U,M) = \left\{\frac{(2M+1)}{2\sigma^2}\right\} exp\left\{\frac{[-M(M+1)]}{2\sigma^2}\right\} \rho(U) \qquad (6)$$

where ρ(U) is the level density and is given by

$$\rho(U) = exp \frac{[2(a(U-E_i)^{1/2}]}{12(2\sigma^2)^{1/2} a^{1/4} (U-E_i)^{5/4}} \qquad (7)$$

III. RESULTS AND DISCUSSION

^{100}Sn is not only extremely rare, it is also magic, according to the shell model of nuclear physics with a magic number 50 among the small handful of magic numbers and ^{100}Sn is therefore doubly magic because it comprises 50 protons and 50 neutrons, and is of particular interest to nuclear physicists as it is the heaviest atomic nucleus, with equal numbers of protons and neutrons. A shape change of ^{100}Sn is predicted with respect to the change in temperature and spin.

The shape of the nucleus is found to be spherical (δ = 0.0, i.e., deformation is zero) and unaltered till the spin J = 20ħ and up to the temperature T = 3MeV. The excitation energy increases with spin and temperature and the occurrence of shape transition beyond temperature T = 1.0MeV is almost at a particular spin (J ≈ 26ħ) (Fig.1) and hence the role of temperature in the shape transition beyond T = 1.0MeV is relatively negligible. The proton and neutron separation energies have its own importance in the isotopic transition. Our calculations show that the proton separation energy decreases with increasing spin and which is around E^* = 14MeV at spin J ≈ 30ħ at all temperatures, which may be correlated to the possibility of transition from S_n to I_n around the spin J ≈ 30ħ. This change may arise from the transformation of a single proton in ^{100}Sn to a neutron via the nuclear process of decay. Around J ≈ 20ħ, the neutron separation energy becomes almost constant, shown in Fig.2, i.e., the particle emission get saturated even if the temperature is increased, and the shape evolution get started slowly. Nuclear reaction calculations based on standard nuclear reaction models play an important role in determining the accuracy of various parameters of theoretical models and experimental measurements. Especially, the calculations of nuclear level density parameters (ldp) for the isotopes can be helpful in the investigation of reaction cross-sections. For ^{100}Sn the level density parameter ”a” calculated at different temperatures are plotted against spin, (Fig.3), which shows a peak at $J \approx 20\hbar$ and T = 0.7MeV, and which increases smoothly with temperature, which reveals the temperature and spin dependent structural effect. The observed peaks refer a shape transition from spherical (δ=0.0) to oblate with minimal axial deformation($\gamma = -180^o$; $\delta = 0.0$). The increase of level density parameter with temperature may be interpreted as a signature for strong residual interaction and the decrease of it with increase of spin may be interpreted as the trend for the collapse of residual interaction.

IV. CONCLUSION

In this work we have followed the statistical approach for the structure study of ^{100}Sn with the aim of exploring the structural changes with respect to temperature and spin. Our study revealed the following conclusions:

1. At all temperatures the ground state deformation is spherical ($\delta = 0.0$).

2. The excitation energy is smooth growing with angular momentum and is increased for increasing temperature and at spin, $J \approx 26\hbar$, there is a shape change from spherical to oblate ($\gamma = -180^o$) is predicted.

3. The decrease of proton separation energy with increasing spin at $E^* = 14$MeV is due to the transition from S_n to I_n via the transformation of a proton in ^{100}Sn to a neutron via nuclear decay.

4. The neutron separation energy decreases with increasing temperature and spin, which shows the stability of the nucleus ^{100}Sn against temperature and angular momentum.

5. A transitional state is predicted at spin $J \approx 20\hbar$ at all temperatures and the shift in ‘a’ with temperature is around 1 MeV^{-1} and which may be interpreted as the signature for strong residual interaction.

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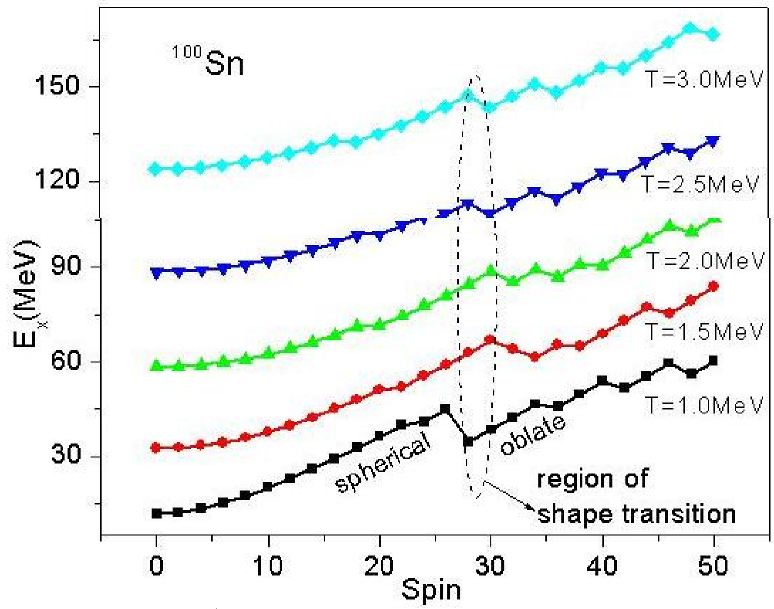

Fig. 1 Excitation energy (E^*) Vs spin plot at different temperatures from T=1.0MeV to 3.0 MeV. The shape transition region is marked as dotted spheroidal shape. The spin is in units of $\hbar$.

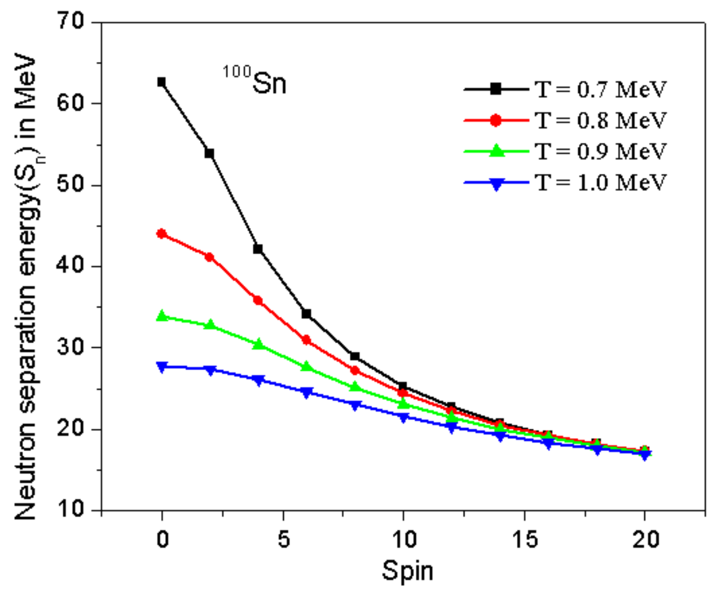

Fig. 2 The smooth variation of neutron separation energy in MeV against spin. The influence of temperature on separation energy decreases with spin and around J=20$\hbar$ the separation energy becomes almost constant for any temperature. The spin is in unit of $\hbar$.

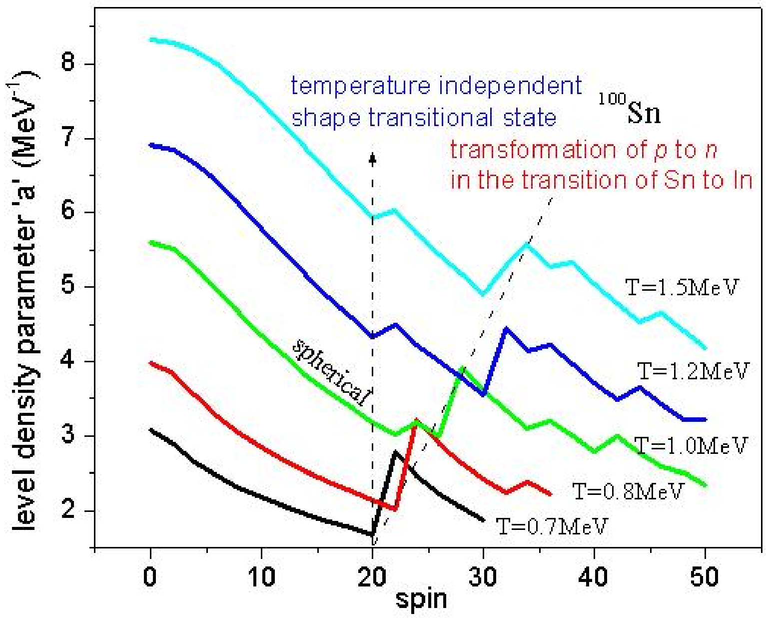

Fig. 3 The decrease in level density parameter with spin and the small peak at J=20ℏ (vertical dashed line) and proportionate increased peak (sloped dash line) shows the transitional regions of shape and particle. The spin is in unit of ℏ.