Microscopic study of Nuclear Level Density and Thermal properties of $^{44, 47, 50}$Ti

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Introduction

Nuclear level density provides information about the structure and thermodynamical properties of highly excited nuclei, and is an important ingredient in statistical model calculation of nuclear reaction cross section, and has many applications from astrophysical calculations to fission or fusion reactor designs. The knowledge of reaction rates is crucial for the understanding of nucleo-synthesis and energy generation in stars and stellar explosions. In many astrophysical scenarios the statistical approach is more reliable [1] since stellar evolution is more as a thermo-dynamical one.

Level densities are affected by pairing of nucleons, that is, under the influence of a short range attractive force, nucleons prefer to form pairs. Nucleon pairs(Cooper pairs) can break up at higher temperatures and these thermal breaking of Cooper pairs leads to increasing level density and entropy[2]. The effect of Nuclear structure upon the value of level density parameter (ldp) can be obtained by considering shell correction, pairing correlations and collective excitation.

Very recently Zhang et al.[3] measured the titanium isotopes in samples from the Earth, Moon, igneous meteorites, etc. and showed that Earth and Moon have essentially the same ^{50}Ti / ^{47}Ti, and which provides clues to the origin of the planets. Hence, a detailed study on ^{44}Ti (N=Z), ^{47}Ti and ^{50}Ti (N>Z) is carried out in this work, in the context of response of entropy, excitation energy and ldp to temperature.

Theory

The nuclei formed in collision may be in excited states and hence their decay or emission for stability will greatly influenced by thermal and collective excitation. Hence a thermodynamical approach, incorporating thermal and rotational excitations, is the appropriate methodology. The statistical theory of hot rotating nucleus can be easily obtained from the grand canonical partition function,

$$Q(\alpha_Z,\alpha_N,\beta,\gamma) = \Sigma\exp(-\beta E_i+\alpha_Z Z_i,\alpha_N N_i+\gamma M_i).$$

The lagrangian multiplier γ plays the same role as the rotational frequency as in the cranking term $\omega.J_Z$. The pair breaking term γ-m_j is temperature dependent and will generate the required angular momentum. The temperature effect creates particle hole excitation. The level density parameter a(M,T) as a function of angular momentum and temperature is extracted using the equation $a(M,T)=S^2(M,T)/4U(M,T)$ where S is the entropy and U is the total excitation energy. The neutron separation energy is obtained from $Sn=-T(\partial \ell_n Q/\partial\alpha_N)(\partial\alpha_N/\partial N)$.

Results and Discussion

In this work cranked Nilsson method is used to obtain the single particle energies. The predicted shape of the isotopes differ with mass number i.e., the ^{44}Ti is in triaxial shape (γ= -140^o) up to temperature T=0.8MeV and becomes prolate (γ= -120^o) at T=0.9MeV. When T increases the axial deformation 'δ' decreases and at T=1.5MeV the nucleus becomes spherical (δ=0) even at higher angular momentum. The nucleus ^{47}Ti is prolate in shape up to T=1.1MeV and became spherical via triaxial at increasing spin 'J'. From T=1.2MeV the nucleus behaves as spherical one up to J=13ħ. The neutron separation energy predicted for the isotopes, ^{44}Ti and ^{47}Ti shows a stability increase against neutron emission beyond spin 8ħ, and T=1.4MeV and 1.1MeV, respectively. But ^{50}Ti shows a spherical shape at all temperatures and J up to 10ħ. Further increase of angular momentum changes the nuclear shape as oblate (γ= -180^o) with δ=0.1/0.2. The energy required to separate 1n from this nucleus decreases with increasing spin and temperature.

In fig.1. the temperature dependence of the excitation energy for ^{44,47,50}Ti is shown. The arrows indicate the possible temperature dependent transitional states. The deviation in caloric curves reflect the structural change of the systems. Fig.2 shows the temperature dependence of entropy 'S' for the isotopes studied. The immediate deviation in entropy plot (T=1.7MeVfor ^{44}Ti; 1.1MeV for ^{47}Ti; 0.9MeV for ^{50}Ti) may be the indication of breaking of Cooper pair[2] and further raise in S is for quenching of pair interaction. The excess of entropy for odd system(^{47}Ti) is seen in the figure(Fig.2) i.e., for odd system many low lying states can be reached without breaking a pair.

In order to describe the thermal damping of shell effects with increasing excitation energy and to obtain correct nuclear level density (NLD), usually the ldp 'a' were taken from microscopic calculations[4]. Hence calculating correct ldp is an essential factor in NLD and spin cut-off parameter calculations. The ldp for ^{50}Ti is a smooth Gaussian due to its spherical shape and ^{44}Ti and ^{47}Ti show sudden raise against temperature (Fig.3) which is the effect of structural change due to temperature. The decrease of the ldp at higher temperature may be due to the evaporation of light particles emitted from the hot nuclei.[5]. The temperature dependent ldp at relatively low temperature can be explained by the collapse of residual interaction and at high temperature, by changes of mean field.

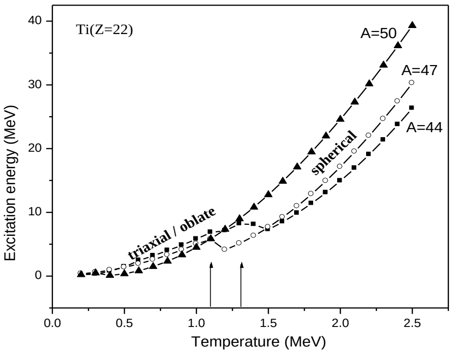

Fig. 1 Caloric curves for $^{44, 47, 50}$Ti nuclei.

In conclusion, the dip/hump in entropy and energy as a function of temperature may be the signatures of the transition from strongly paired state at low temperatures to the unpaired one at higher temperatures, i.e., the pairing phase transition. The decrease of the level density parameter, with increasing values of temperature has to be interpreted as a signature for the collapse of nuclear residual interaction.

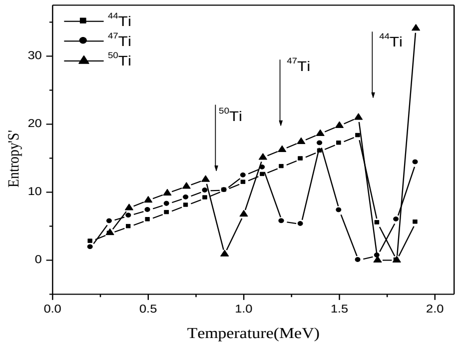

Fig. 2 Dependence of entropy upon temperature for $^{44, 47, 50}$Ti nuclei.

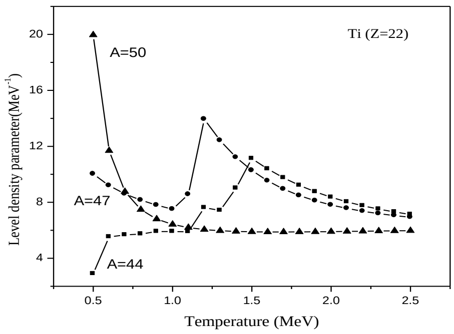

Fig. 3 Variation of level density parameter against temperature.

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