Structural Stability of long lived superheavy nucleus ^{292}122

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Introduction

Recent claims of evidence of the existence of a superheavy nucleus with atomic mass number A = 292 and abundance (1-10)x10^{-12} relative to ^{232}Th in a study of natural Th using inductively coupled plasma-sector field mass spectrometry[1] aroused new enthusiasm about the studies of structural stability of the nucleus with proton number 122 and neutron number 170. In fact larger Z values result in the instability due to the larger coulomb repulsion. But it is well known that closed shells of nucleonic structure give rise to an extra binding which contributes to the stabilization of atomic nucleus [2]. However it has long been predicted that there exist a large number of relatively long-lived superheavy nuclei, the so called superheavy island, which is separated in neutron and proton numbers from the known heavy elements by a region of much higher instability. The stability of superheavy nucleus is determined by many competing decay modes: alpha decay, spontaneous fission, beta decay and etc. The original island of superheavy elements is predicted to be around Z=114 and N=184 [3] mainly due to the fact that ^{184}114 is predicted to be doubly magic nucleus with spherical shape, where shell effect is the strongest. Compound nucleus formed either through cold fusion or hot fusion reaction is at excited state. Information concerning the excited state structure of superheavy nuclei is inadequate, so the testing of structure calculations has been limited. Indeed, detailed knowledge of single particle states is required for the development of reliable nuclear structure models.

The most important structure phenomenon in the compound system is the existence of superheavy elements. Large shell corrections protect superheavy elements against fission. Superheavy nuclei may be deformed or spherical in their ground state, but the compound nuclei between Z=96-112 are deformed. At low excitation energies, level densities are different in spherical and deformed nuclei. Collective enhancement of level densities disappears at higher excitation energies and its exponential damping with excitation energy is described in a formalism by A.V.Ignyatuk [4]. The spherical superheavy elements as well are destabilized against fission by collective enhancement of level densities [5].

The first formulation of level density based on the works of Bethe [6], who calculated the nuclear level density using a thermodynamic relation between entropy and average energy of system considered in the framework of noninteractimg particles of Fermi gas. It uses the assumption that the individual neutrons and protons occupy a set of low energy levels in the ground state and fill up the higher individual states at any excitation energy. This has been successfully used in many works with different contributions made into this model such as shell effects, pairing effects, deformation effects [7-10], finite size effects [11] and thermal and quantal effects[12].

Methodology

The superheavy nuclei formed is in excited state and hence their decay will be greatly influenced by thermal and collective excitation. Hence a thermo dynamical approach which incorporates thermal and collective excitations is required. 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)=S2(M,T)/4U(M,T) where S is the entropy and U is the total excitation energy. The neutron separation energy is obtained from $S_n=-T(\partial lnQ/\partial\alpha_N)(\partial\alpha_N/\partial N)$. In this work cranked Nilsson method is used to obtain the single particle energies.

Results and Discussion

The structural changes of long lived superheavy nucleus, claimed from the study of natural Th, ^{292}122, is studied in the statistical approach[13]. The calculation for the experimentally discovered nuclei in the superheavy region are tested with the experimental findings and the observed shape also exists as per our calculation and so we extend the method to the compound nucleus ^{292}122 for finding the structural stability against spin and temperature. Our calculations reveal that the said nucleus is spherical (δ=0.0) at its ground state with excitation energy less than 1MeV. In this calculation the deformation parameter δ ranges from 0.0 to 0.6 and the spin from $0\hbar$ to $30\hbar$. When the temperature effect is included, the nucleus shows a pronounced shape change from spherical to oblate with deformation, δ=0.1, from the temperature, T=0.3MeV. This effect is observed even at higher temperatures, but from T=1.7MeV to 2.0MeV the system behaves as a spherical one, irrespective of the spin. The shape change observed at temperature T=1.2 MeV in the spin M = $12\hbar$ is shown in the excitation energy Vs spin graph (fig.1). It is quite interesting to see that the change in neutron separation energy is not much and it decreases slightly with increasing temperature. Since the neutron separation energy is always leading the proton separation energy the probability of neutron emission is less and hence alpha decay may be the probable decay mode of this system. As for as the level density parameter is concerned it fits well with the Gaussian fit at lower temperatures and at higher temperatures the deviation with respect to spin is very less (fig.2). This may be because of the interplay of Coulomb and surface energies, the barrier along the deformation path decreases with increasing temperature and decreasing density.

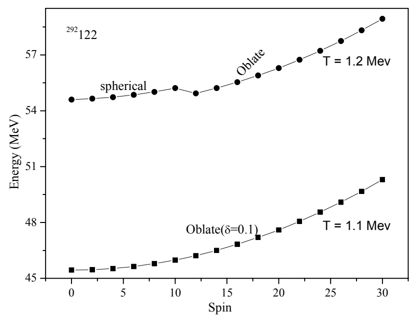

Fig.1 Variation of excitation energy with spin ($\hbar$) at different temperatures

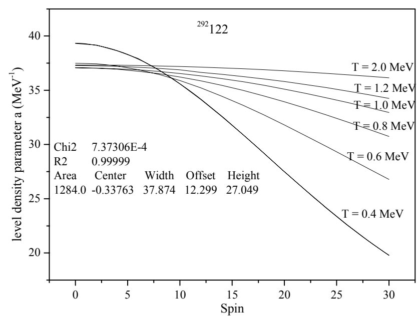

Fig.1 Level density parameter with spin ($\hbar$) at different temperatures

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