Next proton magicity in the island of stability

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Introduction

Nuclei with larger atomic number are produced with accelerator-based experiments, most often via the fusion reaction involving α-particles and heavy ions. In heavy-ion induced fusion reactions new nuclei up to Z=118 were synthesized during recent times [1, 2, 3]. Fusion of actinides with ^{48}Ca leads to more neutron rich superheavy nuclei with longer half life time. Indeed, life times of newly synthesized heavy elements with Z = 108 – 118, increase with increasing neutron content [3]. This is in consistent with theoretical predictions of the island of stability at the neutron number N ≈ 184 and proton numbers around Z = 114, Z = 120, and eventually also Z = 126. Even more neutron-rich nuclei could be produced in multi-nucleon transfer processes.

Predictions on the stability of superheavy nuclei are based either on the Hartree-Fock (HF) studies with some effective interaction chosen out of the existing multitude, or on the more phenomenological, but also more tested, macroscopic-microscopic method. Although these models differ quantitatively, they consistently predict prolate deformed superheavy nuclei with Z = 100 − 112, which is confirmed experimentally for nuclei around ^{254}No [4], and spherical or oblate deformed systems with Z = 114 and N = 174 - 184 [5, 6].

Methodology

Different theoretical approaches predict the spherical magic numbers as Z = 126; 164; 204 and N = 228; 308; 406, in the superheavy region. Rutz et al.[7] proposed some other spherical magic number Z = 120 and N = 172 within the relativistic mean-field model [8] and the non-relativistic Skyrme-Hartree-Fock approach [9]. The analysis for even-even nuclei with Z=90-114 and N=136-168 [10,11] showed how important it is to consider a large multidimensional deformation space for the groundstate properties. The non-axial γ deformation has been introduced in the region of superheavies [12]. The unusual stability with respect to fission of ^{252}Fm is a consequence of the gap in the single-particle level spectra at deformed shapes. The large shell effects for deformed nuclei have changed many ideas about superheavy nuclei. The shell effects are leading to an increase of spontaneous fission half-lives of some nuclei and the dominant decay mode of the heaviest nuclei is α-emission[13,14] instead of fission.

Within liquid drop model or the Yukawa-plus Exponential macroscopic model all nuclei have spherical shapes in the ground state, and the actinide fission fragment mass distributions are perfectly symmetric. The experimentally observed permanent nuclear deformations and fission fragment mass asymmetry can be explained by combining the collective and single particle properties in the framework of the macroscopic-microscopic method developed by Strutinsky[15]. The purpose of this work is to study the deformation energy surfaces in the region of superheavy nuclei. The formation of superheavy nuclei is either through hot or cold nuclear fusion and during this process the internal excitation of the single particles is to be considered effectively. Hence treating the system as a thermodynamical one is more suitable to find out the deformation of the system at different parametric consideration and so the statistical model is followed. Shell corrections to the nuclear free energy are temperature dependent. Nuclear structure effects upon the value of the level density parameter have been considered by the inclusion of shell corrections, pairing correlations and collective excitations.

Results and Discussion

In this study we have taken the range of the nuclei from Z=120 to Z=126 with N=156 to 210.

The shape of the nuclides around mass number A=290-320 for the systems Z=120-123 are spherical and for Z=124-126, the nuclides with A>300 show spherical configuration. Considering the shape transition, the range of the superheavy nuclei from 120-126 may be divided into two parts as, 120-123 and 124-126. The neutron number dependence for all the studied seven systems gave similar effects. The nuclei with Z=120, 121, 122 are having shape transition from prolate deformed to oblate deformed via spherical with increasing neutron number, while the nuclei from Z=124 to Z=126, transition is like a circle such as, triaxial, oblate, spherical, oblate and triaxial(γ= - 160^o; δ=0.2); no prolate deformation is observed in this region. Only Z=123 changes its shape from triaxial to oblate via spherical with increase in neutron number.

The nucleus Z=120 behaves as spherical when N=168-200, and further increase of N makes the nucleus deformed (δ=0.1) in oblate (γ=-180^o)shape. The nucleus $^{290-324}$122 is spherical in shape and decrease in N makes the nucleus prolate deformation (δ = 0.1 ; γ = - 120^o) and increase of N makes it oblate deformed (δ = 0.1 ; γ = - 180^o). Compared to the nuclei Z = 120 - 122, the nuclei with Z = 123 - 126 are more oblate deformed (δ = 0.2 ; γ = - 180^o).

As per the neutron separation energy obtained from the relation $S_N = -\sum_i [n_i^N l_n n_i^N + (1-n_i^N)\ l_n(1-n_i^N)]$ where n_i^N is the average occupation probability for neutron, for the nucleus Z=122, the most stable isotope is ^{302}122, compared to all other isotopes from A= 282 - 320 which coincides with the report of Patra et al.[16].

The grouping of the ground state quadrupole deformation effect of around 350 nuclides in the superheavy region from Z = 120 - 126 is plotted in fig.1. The higher deformations are obtained only either oblate of triaxial state. From the plot it is evidenced that the nucleus Z = 120 is having more isotopes with zero deformation at their ground state than the nucleus Z = 126. Hence, by considering the shape of the nucleus, among the nuclei studied from A = 120 to A = 126, the more stable nucleus seems to be Z = 120 rather than Z = 126, which may be correlated with the next proton shell closure beyond ^{208}Pb; which is in agreement with Adamian et al [17].

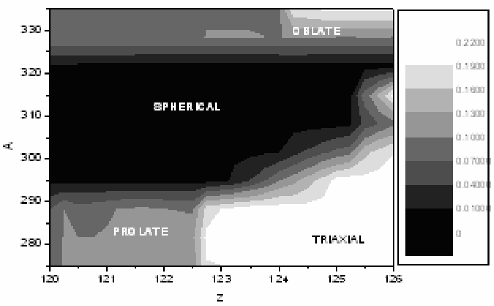

Fig. 1 Calculated ground state quadrupole deformation for SHN

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