Prediction of Next Island of Magicity

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Introduction

The quantum shell effects play an important role in stabilizing heavy nuclei. It was realized and the existence of superheavy elements was predicted in 1960's [1, 2]. The elements beyond Plutonium are artificial and are produced in heavy-ion reactions, mostly by complete fusion. The stability of such excited superheavy nuclei can be studied in two ways as (i) the stability behavior of a superheavy nucleus against excitation, eg., the attenuation of the shell effects with temperature, and (ii) the survival probability of an excited compound nucleus in various channels. Many theoretical works have been reported in these and are giving different results as per the model employed.

Theoretical studies indicated that reasonable candidates for magic number (closed shells), next to the experimentally known nucleus with Z= 82, and N=126, could be Z=114 and N=184 [3,4]. Many calculations done for the properties of nuclei around Z = 114, stimulated works on synthesis and even searching for them in nature. In 1980's the expectation of the existence of deformed superheavy nuclei with half -lives long enough to be observed in experiment has appeared. Some indications for this have come from relatively long spontaneous – fission half lives[5], local minima (on the nuclear chart) of energy (maxima of binding energy) of nuclei[6,7] and relatively long fission half-lives [8-10], obtained in calculations.

As far as the next magicity (proton/ neutron) in the superheavy region is concerned, Z=114 and N=184 is predicted as the most probable magic numbers, but N=184 neutron magicity has not yet been reached experimentally. It is to be mentioned here that the quadrupole deformation is to be treated as one of the main component in predicting/ calculating the structural stability, and which is large (β_2=0.24) and about constant in a large part of the superheavy region, and rapidly decreases as one moves to the boundaries of the superheavy region[11].

Different models consistently predict that elements with Z=100 – 112 are prolate superdeformed and $Z \geq 114$ and N=174 – 184 are spherical or oblate deformed systems[12,13]. The prolate deformation for nuclei around ^{254}No is confirmed experimentally[14]. Cwiok et al.[12], reported that $Z \geq 120$ and $N \leq 166$ is prolate well-deformed ground state (β_2=0.2) but in ref.[13], Z = 122 & N = 166 was reported as slightly oblate (β_2 = -0.12). These calculations were done either by self-consistent calculations with Skyrme process SLy7 and SkP, or with Woods-Saxon results. The experimental values for the deformation of ^{288}122 are less than 0.2. Viewing in this context, the region of superheavy nuclei is broadly grouped into three, ie., nuclei with Z = 100-112, $Z \geq 114$ and $Z \geq 120$.

The statistical model has been used here since the formation of superheavy nuclei is through complete fusion either by cold or hot fusion reactions, which in turn increases the internal excitation. Possible formation of about 150 isotopes of superheavy region are subjected in this study for locating the stable region or 'next magic island'.

Methodology

In this work we have used the statistical model to calculate the energy, level density, separation energy [15] for a given γ and δ values and these values corresponding to the minimum energy is extracted for the ground state deformation.

The Conservation equations in terms of single particle level for the protons ε_i^Z with spin projection m_i^Z and neutrons ε_i^N with spin projection m_i^N [16] are

$$\langle Z\rangle = \sum n_i^Z = \sum [1 + \exp(-\alpha_Z + \beta\varepsilon_i^Z - \gamma m_i^Z)]$$

$$\langle N\rangle = \sum n_i^N = \sum [1 + \exp(-\alpha_N + \beta\varepsilon_i^N - \gamma m_i^N)]$$

$$\langle E(M,T)\rangle = \sum n_i^Z\varepsilon_i^Z + \sum n_i^N\varepsilon_i^N$$

$$\langle M\rangle = \sum n_i^Z m_i^Z + \sum n_i^N m_i^N$$

where n_i is the occupation probability.

The above equations fix the Lagrangian multipliers. The Lagrangian multiplier γ plays the same role as the rotational frequency as in the Cranking term $\omega.J_z$ of the Cranked Nilsson Hamiltonian [17], in fact for biaxial deformation, they are numerically equal when $T \to 0$.

Results and Discussion

The nuclei ranging from Z=100-108 behaves as a prolate deformed ($\gamma = -120^{o}$; $\delta\approx0.2$) at their ground state and Z= 110 - 114 as prolate deformed ($\gamma = -120^{o}$) with $\delta\approx0.1$, but when we add more neutrons, N>164, the system becomes spherical. A triaxial deformation(($\gamma = -140^{o}$; $\delta\approx0.1$) is obtained for the system Z=118 for very few mass numbers. The system Z=120 & 122 are in spherical shape at its ground state.

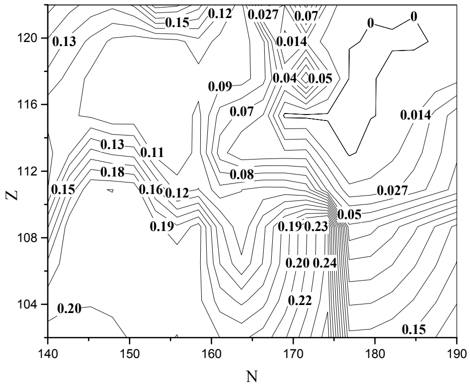

Fig.1 Contour map of the ground state deformations plotted as functions of proton (Z) and neutron(N) numbers. Numbers at the contour lines give the values of the deformations.

Hence the grouping of superheavy nuclei may be, Z = 100 - 108, 110 – 114 ($N \leq 162$), 114 ($N \geq 164$) - 118 and $Z \geq 120$.

From the fig.1, it is evident that most of the investigated nuclei are deformed. Only one, relatively small region of spherical nuclei appear close to N= 172-184 and it is noted from this figure that, for Z=114, N=176 is the most suitable neutron number giving more stability since it is spherical in shape ($\delta\approx0.0$). The particle separation energy of this nucleus [15] is also found high.

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