Nuclei beyond the island of stability

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Introduction

The synthesis of very heavy elements in recent years created an interest on the study of nuclei in the island of stability, which is of prime importance because of the expectation of superheavy elements in celestial bodies. Recently experiments aiming at discovering new elements beyond Z=118 dominate the SHE research at GSI. In view of this, to know about the nuclei beyond the island of stability, the theoretically predicted next proton magic nucleus Z=164, is studied in this work.

Even from the Middle of the 20^{th} Century the physicists discussed about the existence of superheavy nuclei in cosmic rays or supernovae. In 1969, Nilsson, Thompson and Tsang[1] discussed about the possible occurrence of superheavy nuclei in nature. Bandyopadhyay and Chaudhuri [2]also proposed in 1970, neutron stars (pulsars) as the sources of superheavy nuclei with $Z\geq110$ in primary cosmic rays.

Bagulya et al [3]were detected Three superheavy nuclei , whose charge is within the range of Z=105-130 while studying chemically etched tracks of heavy nuclei in olivine from pallasite meteorites and thus validated the theoretical predictions about the occurrence of superheavy nuclei in nature. Very recently Zagrebaev et al.[4] also estimated the possibility of production of superheavy elements in the astrophysical r process.

To our interest, it is found that Ohnishi and Okamoto [5] has studied the nuclear structure properties of neutron magic numbers 184, 228 and 308 and proton magic number 114 and 164, and reported that the upper mass limit of the r-process depends strongly on the magic numbers, especially the neutron numbers.

In this work we mainly concentrating on the Z=164 nucleus which is expected to be the reference nuclei to the next island of hyperheavy nuclei beyond the island of stability.

Methodology

The binding energy per nucleon for the isotopes considered (N=180-390) is calculated through the Droplet model mass formula[6].

The single nucleon separation energies and two nucleon separation energies are calculated through Binding energy formalism.

The single particle level devels are obtained through cranking model and the level density, and entropy are obtained through statistical model. The spin cut-off parameter is calculated using our modified formula[7].

Results and Discussion

Calculating the BE/A of the isotopes of Z=164 from N=180 to N=390 (lies along the beta stability region) suggests the maximum binding is from N=250-270 (>6.1MeV). Concentrating this region, suggests that these nuclei are greatly unstable since single proton binding energy (ε_p) is negative(Fig.1), using statistical model calculations.

The neutron drip line (ε_n=0) determines the limit of existence of neutron rich nuclei and the zero proton binding energy(ε_p=0) determines the limit of existence of proton rich nuclei [8]. The positive value of ε_n (Fig.1) gives a pseudo effect on neutron binding, due to the non existence of these isotopes. Hence one can concentrate on the competition between the surface energy and the coulomb energy. A very high surface energy compared to coulomb energy (3:1) is obtained and which is practically impossible. But for N=184, both ε_p and ε_n are positive(>0) and hence the probability of existence of $^{348}164$ is high.

Bohr and Wheeler [9] established a limit (Z^2/A) ≈ 48 for spontaneous fission. In this context, $^{250\text{-}276}164$ are having the value of fissionability parameter (Z^2/A)=60-64, and for N=184, (Z^2/A)=77, which indicates the nuclei are unstable against spontaneous fission.

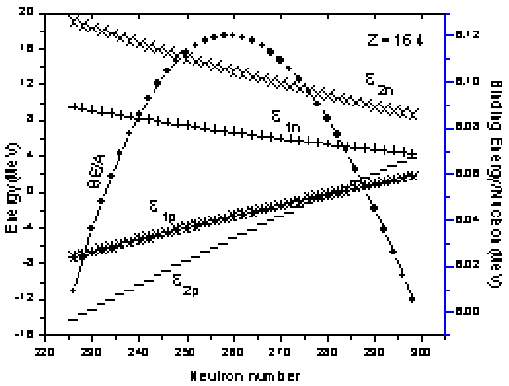

Fig.1. Characteristics of nuclei in the β-stability region

The shell structure of a nucleus is a sensitive function of its deformation. The isotopes of the nucleus with N=250-276 show a fluctuating shape (prolate, oblate & triaxial) with δ=0.1 at T=0.5MeV and spherical at T=1.0MeV. In contrast the nucleus with proton magic 164 and expected neutron magic 184, shows a spherical shape at all temp., upto 3MeV. A small increase in the level density parameter 'a' is observed at low temp. and at higher temp. it is almost saturated (Fig.2). The excitation energy(E_x) of $^{184}164$ increases smoothly with temp., but for N=250-276 E_x is almost constant, and hence the stability of these nuclei gets vanished. The level density increases with temperature and at T>1MeV, it became infinite, and this may be the indication of reaching the nucleus to plasma state. Hence our study reveals the survival of $^{184}164$ upto T=1MeV, which suggests the nuclei beyond island of stability will lie along or near to N=Z line. Thus possibility of occurrence of hyperheavy nuclei in supernovae is high since supernovae generally contain material with equal numbers of neutrons and protons.

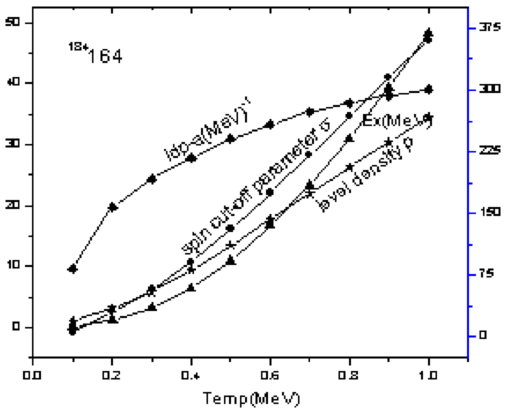

Fig.2. Characteristics of nuclei along/close to the N=Z line.

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