Prediction of temperature limit for hot rotating magic SHN

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Introduction

The survival of the nuclei at different physical conditions is one of the very basic criteria in the field of nuclear physics. Many nuclei especially far from stability are expected to be formed during supernova explosions either through r- or rp-process. After the discovery of $Z \leq 118$, formation and detection of nuclei with bigger Z is one among the main objectives of nuclear physicists. It is known that nuclei featuring magic nos. of nucleons are more stable than their neighbors. The relativistic Hartree-Bogolyubov theory determined the possible proton magic nos., as Z=106, 114,120,126,132 & 138 and neutron magic nos. as N=138, 172, 184, 198, 216, 228, 238, 252, 258 & 274 [1]. In this paper we discuss about the possible existence of the predicted superheavy nuclei with proton magic numbers 132 and 138, in the vicinity of stellar nucleo synthesis, ie., the maximum temperature of nuclear existence.

Methodology

The nuclei in the SHN region may be formed during supernova explosions through r-process and hence the formed system must be treated as a thermo dynamical one. So the statistical theory incorporating temperature and rotation is more appropriate one. In this work we have followed the statistical theory by treating the nuclei as a hot system. The statistical code developed by us is executed for the numerical values, such as, T=0.1-2.0Mev(0.1); spin J=0-60$\hbar$; γ = -180^o to -120^o(10^o); and δ=0.0-0.6.The BE/A is calculated using the droplet model [2] and obtained a higher value for N=200 for Z=132 and N=210 for Z=138 as E_B=6.77158MeV and 6.64661Mev respectively. Comparing the said two nuclei Z=132 is always having higher BE/A for the range of N=170-188, but high E_B alone does not provide stability to the nucleus as for as the nuclei synthesized in the chemical evolution of stellar nuclear processes.

Results and Discussion

Z=132: At T=0.5MeV the neutron separation energy(S_n) decreases smoothly with increases of spin for the nuclei with N=172-178, but when N=180, the S_n shows an increasing trend. S_n has the maximum value of 16.15MeV at 0$\hbar$ in this range of nuclei. While increasing the temperature S_n value get decreases as neutron exhibits local minima at N=164 and around 1-1.8MeV at T=1.0MeV, and 2MeV at higher temperatures. Such a fluctuation of S_n at low spins at T=1.0MeV pronounces the maximum possible temperature of the system may be 1.0MeV.

The ldp is a smooth Gaussian for N=172-186 at T=0.5MeV, but at N=188, a shift at 44$\hbar$ and another at 62$\hbar$ is observed. At higher temperatures, ie., 1.0-2.0 MeV a shift at J>20$\hbar$ is obtained for N=172-178. Nucleus with N=180 shows a shift at J=10$\hbar$ and the corresponding shift at a particular temperature increases slowly for higher N, Such an effect is observed in E_x also, and which resembles in the shape of the nucleus studied.

It is oblate deformed (γ=-180^0, δ=0.1) at low spins for N=172-178 at $T \leq 1.0$MeV. At higher spins the deformation is increased from δ=0.1 to 0.2. But at T>1.0MeV the system behaves like a spherical one at low spins (J<30$\hbar$) and oblate deformed at higher spins. If N is added ie,N=180-186, a spherical shape is predicted at T=1.0MeV. At T=0.5MeV, an oblate shape is predicted irrespective of the spins but the deformation increases with increase of spin. At higher temperatures, T>1.0MeV, all the nuclides studied show a spherical shape at lower spins, (J=0-30$\hbar$), and become oblate deformed.

At J=0$\hbar$, a drastic difference in shape is observed for N>160 when $T \leq 0.5$MeV, ie., for

$N<210$: $\gamma=-180^0$, $\delta=0.2$and $\gamma=-120^0$, $\delta=0.2$ for $N<232$. For $N=234$: $\gamma=-180^0$, $\delta=0.1$ and $210<N<230$: $\gamma=-160^0/-140^o$, $\delta=0.1$. Spherical nuclei are observed for N=180-198, N=182-206, and N=180-208 at T=0.7MeV, 0.9MeV and 1.0MeV respectively. At T>1.0MeV a spherical shape is observed irrespective of N.

Z=138: At T=1.0MeV, a drop in S_n is observed at low spins and which increases further for N>198. But a continuous decreasing effect is observed when 238<N<198. And at T>1.0MeV the S_n seems to be constant. ie, the change in S_n is too small. Such a trend in ldp also observed at T>1.0MeV, the trend of the ldp is entirely different at T<1.0MeV and at this temperature a fluctuating trend is observed when 238>N>198 and which is a smooth Gaussian for 238<N<198.

The nucleus Z=138 shows an oblate shape ($\gamma=-180^0$; $\delta=0.1/0.2$) at T=0.5MeV when N=170-190 from spin J=0-60$\hbar$. Increasing N shows a shape fluctuation with spin, ie., N=192,194 is spherical at low spin and becomes oblate. N=196, 198 are oblate at J<12$\hbar$ and become spherical at 14$\hbar$<J<30$\hbar$ then to oblate. A triaxial shape is predicted at low spins for N=200-236 and its shape fluctuates from prolate to oblate via triaxial with spin. An oblate shape with deformation $\delta=0.2$ is predicted for N>238 at all spins. When T=1.0MeV, N=160-164 are prolate at lower spins and become oblate deformed via triaxial, but N=166-176 are oblate deformed and N=178-208 are spherical. It is interesting to note that the shape transition of the highest BE/A nucleus, ${}^{348}138_{210,}$ is quite different than the neighbouring isotopes. The spherical shape obtained at N=178, may be correlated with the proton shell correction exhibiting shallow local minima at Z=120 and 138 and the shell correction for N=164 and 178, reported by Denisov[3]. At higher temperature T=1.5MeV and 2.0MeV, there is no shape dependence with spin and temperature for all isotopes. Hence the limiting temperature for the nuclei with such a heavy mass formed in supernova explosions may be ≈1.0MeV and which is the ideal temperature in statistical theory to understand the characteristics of such nuclei with very less life time. The E_x Vs N plot (fig.1) for Z =132 and 138 at T=1.0MeV is plotted and which shows the most probable shape of the isotopes at spin J=0$\hbar$.

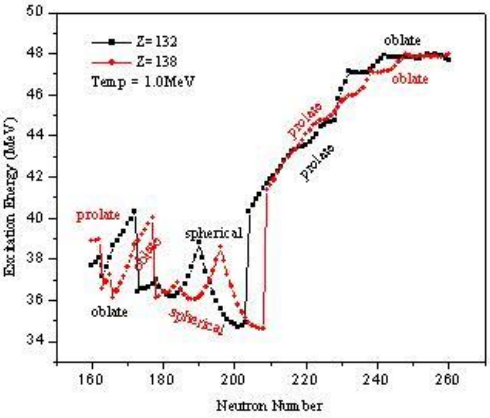

Fig. 1 Probable shape of nuclides at spin 0$\hbar$

To find the most probable nuclei with spherical shell closure, the ldp, nld are calculated and the ldp Vs N plot (fig.2) for different temperature show minima at N= 166, 174, 200, 220, 234 and 244 which are very close to the predicted next neutron magic numbers[1]. But at T>1.0MeV the ldp value is very less and is almost constant for all the isotopes considered. Hence a thermal evolution beyond T=1.0MeV is hardly possible for these nuclei since at higher temperatures the nucleus may be in plasma state.

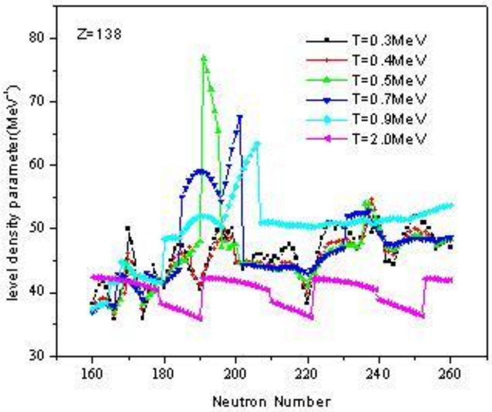

Fig. 2 Variation of 'a' against n^o addition

References

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