Level density and survival of doubly magic SHN beyond Z=120

S. Santhosh Kumar[1,*], P. Preetha[2] and A. Victor Babu[3]
[1]Department of Physics, Tagore Arts College, Puducherry-605008, U. T. of Puducherry, INDIA
[2,3]Research Department of Physics, Bharathiyar University, Coimbatore-606060, Tamil Nadu, INDIA
* email: santhosh.physics@gmail.com

Introduction

The increasing survival probabilities with increasing proton number of superheavy elements from Z=114 to Z=118 seem to indicate enhanced shell effects with increasing Z and therefore a possible proton magic shell may emerge beyond Z≥120. The phenomenological studies of BE(2) systematic[1] and of the persistence of the Wigner term in masses of heavy nuclei[2] indicate Z=126 as the next spherical proton magic number after lead. Self consistent and relativistic mean field calculations predict proton magicities for Z=114, 120, 124 and 126. In ref.[3] it is pointed out that the pronounced central depressions in the densities lead to the spherical shell gaps at Z=120 and N=172 as a direct consequence of a large PS splitting, where as a flatter density profile favours the shell occurrence at N=184 and Z=126. But the relativistic Hartree-Fock-Bogoliubav approach[4] could not predict Z=126 as a proton magic number, instead 120 and 138 beyond ^{208}Pb.

Methodology

In this paper we follow four major steps to identify the possible neutron magic number for the proton magic nucleus Z=126; (i) Considering the system as a thermo dynamical one, since the compound nucleus formed either through hot or cold fusion may be in excited state and hence their decay will be greatly influenced by thermal and collective excitation, and hence a statistical model approach is essential with temperature effect, for which a code is written and from which analyse the neutron binding, which is an important feature of SHN,(ii) Systematic analysis of the behavior of the nucleus at high level densities since the density of nuclear levels provides information about the structure of highly excited nuclei and is also a basic quantity in nuclear reaction theory, (iii) Survival against α-decay, the most prominent decay mode of SHN. For an enhanced stability, the α-decay half lives are expected to be larger than its neighbours, and (iv) The shape of the nucleus, since the nucleus can form a closed shell configuration for protons as well as for neutrons leading to extra stability for doubly magic system.

Results and Discussions

Nuclei with high stability possess larger binding energies. The neutron binding energy for the nucleus Z=126 is calculated using the formula [5] $S_N = TN/\{\sum_i[(1 - n_i^N)n_i^N]\}$, for a range of neutron numbers N=160-260. The neutron binding or separation energy(S_N) must be high for magic nuclei. The calculation is performed for a range of temperatures T=0.1-2.0MeV and the plot for S_N and logarithmic value of level density pronounces the possible neutron magic numbers. The nuclear level density is calculated using Bethe formula, $\rho(E)=\{\pi^{1/2}/12a^{1/4}E^{5/4}\}\exp(2(aE)^{1/2})$.

One can easily identify the magic neutron numbers by the drop in level density as well as the odd-even staggering effect. The level density and S_N against various neutron numbers at T=0.2MeV is plotted in Fig.1. The drop in level density as well as the rise in S_N indicates the possible magic neutron numbers. When the temperature increases the drop in level density remains at N=184 and 238, which implies the presence of shell gaps even at high temperatures. But the drop at other numbers disappear with increase of temperature and become almost smooth at T=1.0MeV, which shows the instability of these nuclides against temperature. When T=0.5MeV, the drop in level density occurs at N=176, 184, 200 and 238, but at T=1.0MeV, the drop at N=176 & 200 disappeared and so ^{302}126 and ^{326}126 are not stable as ^{310}126 and ^{364}126. The formation and survival of the nucleus $^{364}126$ may be validated through Q-value of the reaction and α and SF decay studies.

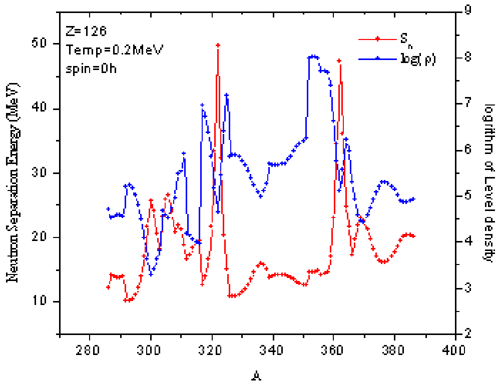

Fig. 1 Neutron separation energy and level density of Z=126 with a range of neutron. The drop in level density indicates the possible neutron shell closures.

The α-decay half life of the predicted doubly magic nuclei, $^{310}126$ and $^{304}126$(the half life is very less as per our study and exists only at very low temperatures since level density drop occurred at N=178 when T<0.5MeV), are calculated with the Brown formula[6] $\log_{10}(T_{1/2})=9.54(Z-2)^{0.6}/(Q_\alpha)^{1/2}-51.37$, and is compared with the GLDM model[7] for which the data are available. Our modified Q_α [8] is used in this formula to predict most accurate half life value. Our results show a close agreement with the GLDM results which is shown in Fig.2. The $T_{1/2}$ of the α-decay products have long life time than their parent nucleus, in these series.

Since the nuclear shape also determines effectively the stability of the nucleus, the inclusion of angular momentum in the model studied provides the possible shapes of nuclides at different spins. When the spin is $0\hbar$ the isotopes of Z=126 are at different shapes. Nuclei with N=184-200 are spherical (δ=0.0) at T=0.5MeV and N=160-182 & N=202-208 are oblate deformed ($\gamma=-180^o$;δ=0.2). N=210-218 are in triaxial shape either -160^o or -140^o with δ=0.2 and N=220-234 are in prolate shape ($\gamma=-120^o$;δ=0.1). The neutron number N=238 falls in the range N=236-260, and are in oblate shape ($\gamma=-180^o$;δ=0.2). This structural evidence also supports the argument of survival of such a huge neutron magic number for the nucleus Z=126 at high temperatures and hence the probability of undergoing SF is less.

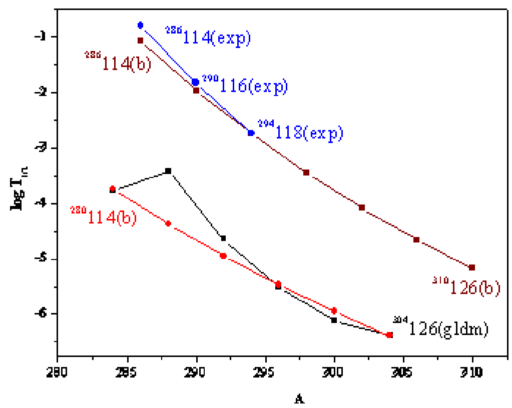

Fig. 2 The α-decay half of chain of decay products of $^{310}126$ and $^{304}126$, in comparison with available experimental data.

Conclusion

To conclude, the level density, single neutron separation energy and probable shape at different temperatures pronounce the neutron magic number for Z=126 is 184. The interplay between the binding energy and nuclear level density is also discussed in the context of stability of the theoretically predicted SHN.

References

[1] N. V. Zamfir et al., Phys. Lett. B357 (1995) 515.

[2] N. Zeldes, Phys. Lett. B429 (1998) 20.

[3] A. V. Afanasjev and S.Frauendorf, Phys. Rev. C71 (2005) 024308.

[4] J. J. Li et al., Phys. Lett. B732(2014)169.

[5] M. Rajasekaran et al., Phys. Rev. Lett.61 (1988)2077.

[6] B.A.Brown, Phys. Rev. C46(1992)811.

[7] A.Dasgupta-Schubert and M.A.Reyes, At. Data. Nucl. Data Tables 93(2007)90.

[8] S.Santhosh Kumar and A. Victor Babu., Proc. DAE Symp. on Nucl. Phys. 59 (2014) 540.