Relativistic mean-field description of some traditional neutron magic isotones

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The relativistic mean-field (RMF) approach has been extensively applied for the description of the ground state properties of nuclei located in various regions of the nuclear chart with remarkable success [1–5]. The main advantage of the RMF approach over other non-relativistic theories is that it provides the spin-orbit interaction in the entire mass region in a natural way which is very crucial to study the unstable nuclei near the drip-line. In this communication we present a brief description of the part of the results obtained in extensive study of the nuclei constituting the isotonic chains for the traditional neutron magic numbers N = 8, 20, 28, 50, 82 and 126, as well as 40. These studies have been carried out within the framework of relativistic mean field plus state dependent BCS approach [5] including the deformation degree of freedom [6](throughout referred to as deformed RMF+BCS).

Similar to the situation met in the case of isotopes of proton magic nuclei [5], it is found that the wave function of single particle proton resonant states lying in the continuum close to the proton Fermi level in the proton rich isotones near the proton drip-line with neutron number N = 28, 50, 82 and 126 as well as 40, have characteristics similar to the wave function of bound proton single particle states. Due to this the pairing interaction can connect the resonant states with the bound ones resulting in the increase of total pairing energy. This phenomenon plays an important role in accommodating a few extra particles in the resonant states resulting in an extended proton drip-line . However, contrary to the large extension of the neutron drip-line in the case of proton magic nuclei due to the ability of accommodating many neutrons by the low lying high angular momentum single particle neutron resonant states, here in the case of magic isotones the addition of more protons for a fixed neutron number is strongly restricted by the disruptive effect of the Coulomb force amongst protons. Besides this restriction, it may be emphasized that the similarity of wave functions does make the overlap of the bound and continuum resonant states appreciably large as can be seen from Fig. 1 which shows the pairing gap energy of the proton single particle states for the nuclei near the proton drip-line of the isotonic chains with neutron number N = 40, 50, 82 and 126. These proton rich nuclei are, respectively, $^{84}_{44}$Ru$_{40}$, $^{96}_{46}$Pd$_{50}$, $^{154}_{72}$Hf$_{82}$ and $^{220}_{94}$Pu$_{126}$.

Indeed, the figure shows that the pairing gap energy values of the continuum resonant states is about 1 MeV which is close to that for the bound states. To elaborate, in the case of proton rich nucleus $^{84}_{44}$Ru$_{40}$ located close to the proton dip-line for the N = 40 isotonic chain, the important resonant state is the low lying proton 1g$_{9/2}$ single particle state at $\epsilon =$ 0.42 MeV and accommodates about 4.3 protons. The other resonant states, though less significant, are found to be the proton single particle states 2p$_{1/2}$, 2p$_{3/2}$, 1f$_{5/2}$ and 1f$_{7/2}$ as shown in Fig. 1. Similar characteristics of other proton rich nuclei representing different isotonic chains are also seen from the figure. Calculations for the N = 126 isotonic chain suggest that the proton 1i$_{13/2}$ single particle state plays an important role as a resonant state. This is illustrated in Fig. 1 for the drip-line nucleus $^{220}_{94}$Pu$_{126}$. For this nucleus the resonant 1i$_{13/2}$ state lies at $\epsilon = 1.00$ MeV, whereas the proton Fermi energy is seen to

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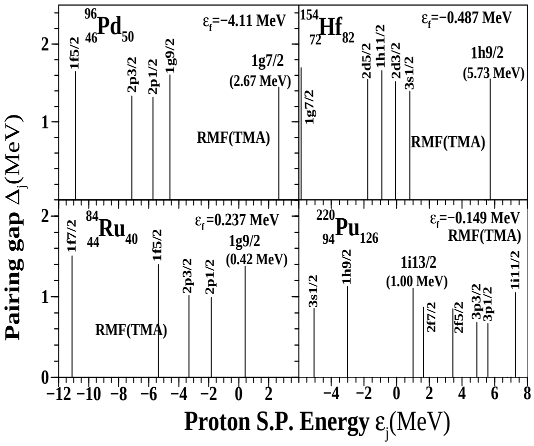

FIG. 1: Pairing gap energy Δ_j of proton single particle states with energy close to Fermi surface for the proton rich nuclei $^{84}_{44}\mathrm{Ru}_{40}$, $^{96}_{46}\mathrm{Pd}_{50}$, $^{154}_{72}\mathrm{Hf}_{82}$ and $^{220}_{94}\mathrm{Pu}_{126}$ close to the proton drip-line for the isotonic chain with neutron number N = 40, 50, 82 and 126 respectively.

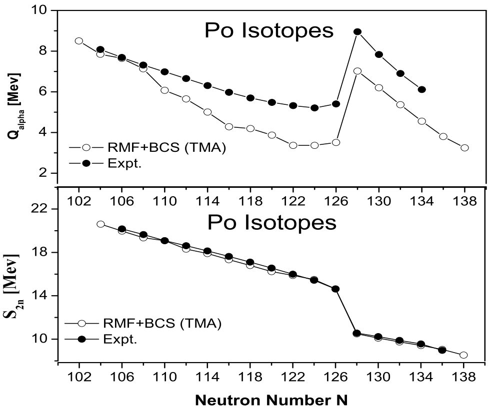

FIG. 2: Calculated two-neutron separation energy S_{2n} (lower panel) and alpha decay energy Q_α (upper panel) for the Po isotopes are compared with the available experimental data [7] as a function of increasing neutron number N. The abrupt change in both the plots signifies the shell closure at the neutron number N = 126.

be at ϵ_f = -0.15 MeV. Again, it is seen that the pairing gap energy of the resonant $1i_{13/2}$ state has a value $\Delta_j \approx 1.5$ MeV, which is close to that of bound states. The magicity at the neutron number N = 8, 28, 50, 82 and 126 as well as 40 can be seen from the detailed behaviour of single particle wave functions and their energies, pairing gaps, total pairing energy etc. For example, fig. 2 shows for the Po isotopes the variation in the two neutron separation energy S_{2n}, and that in the alpha decay energy Q_α as a function of increasing neutron number. An abrupt change at N = 126 in the two plots is clearly seen. It signifies the evolution of shell closure in the Po isotopes at the neutron number N = 126. The figure also shows the available experimental data [7] for the two-neutron separation energy S_{2n}, and the alpha decay energy Q_α. The deformed RMF+BCS results for the S_{2n} values are seen to be remarkably close to the experimental data. Though the calculated Q_α values are slightly lower than the experimental values [7], the trend in its variation with increasing neutron number N is indeed very close to that of the experimental data [7].

Acknowledgments

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