Study of N=28 Isotones within RMF+BCS Approach

G. Saxena[1,2], D. Singh[1], and H. L. Yadav[3*]
[1]*Department of Physics, University of Rajasthan, Jaipur - 302004, INDIA*
[2]*School of Engg. and Tech., Jaipur National University, Jaipur, -302025, INDIA and*
[3]*Physics Department, Banaras Hindu University, Varanasi - 221005, INDIA*

Introduction

Experiments with radioactive nuclear beams provide the opportunity to study very short-lived nuclei with very large isospins [1]. Theoretical descriptions of drip line nuclei in terms of mean field theories [2–4], both nonrelatistic as well as relativistic mean fields (RMF), have been well received. Recently it has been shown [5, 6] that the relativistic mean-field (RMF) plus BCS approach wherein the continuum has been replaced by the discrete single particle states for the calculation of the pairing energy provides an alternative fast approach to the relativistic Hartree-Fock-Bogoliubov (RHB) description of the drip-line nuclei. In the analogy of our previous publication on proton magic nuclei [5], we have employed RMF+BCS approach for the study of neutron magic nuclei with neutron number N = 28 near the drip-line.

Potential and Radial Wave Function

Before we describe the details of our results, first we demonstrate the effect of low lying resonant states in providing stability to the system near the proton drip-line, and consequently in accommodating more protons and give rise to extended two proton drip line up to Z = 30. For the N = 28 isotonic chain we have chosen the nucleus ^{58}Zn as a representative example of the proton rich N = 28 isotone. In the upper panel of Fig.1 we have displayed the calculated RMF potential, a sum of scalar and vector potentials, along with the spectrum for the bound proton single particle states for the proton rich ^{58}Zn obtained with the TMA force [2]. The figure

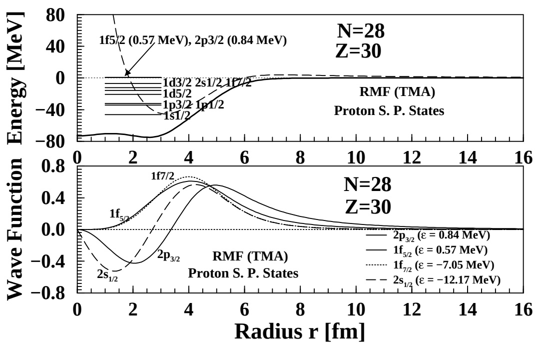

FIG. 1: Upper panel: The RMF potential energy (sum of the scalar and vector potentials), for the nucleus ^{58}Zn as a function of radius is shown by the solid line. It also shows the energy spectrum of some important proton single particle states including that of the resonant $1f_{5/2}$ and $2p_{3/2}$ states.
Lower panel: Radial wave functions of a few representative proton single particle states with energy close to the Fermi surface for the nucleus ^{58}Zn. The resonant $1f_{5/2}$ and $2p_{3/2}$ have been shown by solid lines.

also shows the positive energy low-lying proton resonant $1f_{5/2}$ and $2p_{3/2}$ states close to the Fermi surface. These states play significant role for the binding of proton rich isotones through their contributions to the total pairing energy. The total mean-field potential for the proton $1f_{5/2}$ state, obtained by adding the centrifugal potential energy has also been depicted (dashed line) in the upper panel of Fig.1. It is evident from the figure that the effective total potential for the $1f_{5/2}$ state has an appreciable barrier to form a quasi-bound or resonant state. Such a meta-stable state remains mainly confined to the region of the potential well

*Electronic address: `hlyadav_2000@yahoo.com`

and the wave function exhibits characteristics similar to that of a bound state. This is clearly seen in the lower panel of Fig.1 which shows the radial wave functions of some of the proton single particle states lying close to the Fermi surface (proton Fermi energy $\lambda_p = -0.097$ MeV). These include the bound $2s_{1/2}$ and $1f_{7/2}$ states in addition to the states corresponding to the resonant $1f_{5/2}$ and $2p_{3/2}$. The wave functions for the $1f_{5/2}$ and $2p_{3/2}$ states in Fig.1 (lower panel) are clearly seen to be confined within a radial range of about 8 fm, akin to bound states, characterizing resonant states. Such states have a good overlap with the bound states near the Fermi surface leading to significant value for the pairing gap and also contribute to the total pairing energy of the system near the drip-line.

Pairing Gap and Occupancy

The features described above for the proton resonant states are also supported by their pairing gap energy Δ_j. As seen in the upper panel of Fig. 2 for the proton single particle states in ^{58}Zn, the gap energy for the $1f_{5/2}$ and $2p_{3/2}$ states is seen to have a value close to 1 MeV which is quantitatively similar to that of the bound states, for example, proton $1f_{7/2}$ and $2s_{1/2}$ states. The lower panel in Fig. 2 shows the energy variation of the proton single particle states $1f_{5/2}$ and $2p_{3/2}$ with increasing proton number Z for the N = 28 isotones This figure also shows the occupancy of these states as a function of Z. For Z = 28 and N = 28, shell closure is obtained.

For Z = 30, with addition of two more protons to Z = 28, N = 28 isotone, however, it is found that the proton single particle states $1f_{5/2}$ and $2p_{3/2}$ though partially occupied do not remain bound anymore. Instead, being very close to the proton Fermi level, these two states become resonant state resulting in the bound nucleus $^{58}_{30}$Zn. The isotone $^{58}_{30}$Zn is just bound since the two proton separation energy is now only 0.4 MeV. However, a further addition of two more protons to Z = 30, N = 28 isotone does not give rise to a bound nucleus $^{60}_{32}$Ge, since now the resonant states lie a little away from the Fermi level in the continuum. For this isotone the two proton separation energy becomes -1.1 MeV and the system may be considered just unbound.

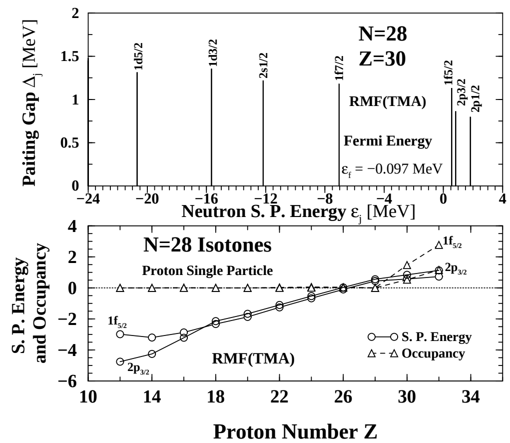

FIG. 2: Upper panel: Pairing gap energy Δ_j of proton single particle states for the nucleus ^{58}Zn. Lower panel: Variation of energy shown by open circle, and occupancy (no. of protons occupying the levels) depicted by triangles for proton $1f_{7/2}$, $2s_{1/2}$ single particle states in N = 28 isotones.

Acknowledgments

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