RMF+BCS description of two-proton radioactivity in $^{42}_{24}$Cr

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Inspired by recent experimental studies of two-proton radioactivity in the light-medium mass region[1–5], we have employed relativistic mean-field plus state dependent BCS approach[6] including deformation degree of freedom[7] to study the ground state properties of selected even-Z nuclei in the region 20 ≤ Z ≤ 40. The results of our extensive calculations show that the nuclei ^{38}Ti, ^{42}Cr, ^{60}Ge, ^{63,64}Se, ^{68}Kr, ^{72}Sr and ^{76}Zr satisfy the criteria $S_p > 0$ and $S_{2p} < 0$[8]. These nuclei are, therefore, expected to be the potential candidates for exhibiting the two-proton radioactivity in the region 20 ≤ Z ≤ 40.

From amongst the predicted two-proton radioactive nuclei mentioned above, we have chosen the nucleus ^{42}Cr which has the near spherical shape (β_{2m} = -0.17) to describe its detailed properties approximately within the framework of RMF+BCS approach for spherical shapes. Such description provides a greater insight for the structure of the nucleus in terms of its single particle energy, wavefunction, pairing energy and pairing gaps etc. This approximate treatment, though not fully justified, is expected to shed light as regard to its finite life time even though it is located beyond the two-proton drip-line.

In order to demonstrate the physical situation of proton rich $^{42}_{24}$Cr$_{18}$ nucleus, we have plotted in Fig. 1 the RMF potential and the single particle energy spectrum for the bound proton single particle states. The figure also depicts a few positive energy proton states in the continuum including the resonant state $1f_{7/2}$ at energy 0.77 MeV. We have also shown in Fig. 1 the total mean-field potential for the resonant $1f_{7/2}$ state, obtained by adding the centrifugal potential energy.

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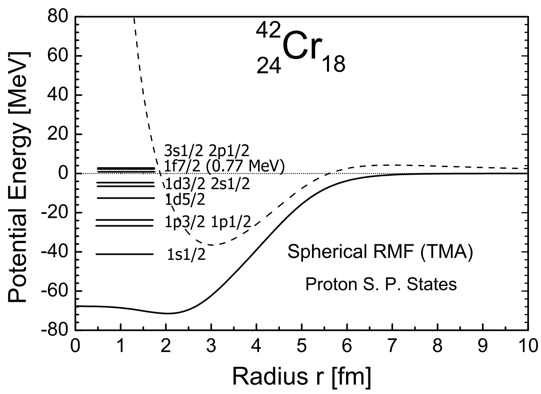

FIG. 1: The RMF potential energy (sum of the scalar and vector potentials) for the nucleus $^{42}_{24}$Cr$_{18}$ as a function of radius is shown by the solid line. The long dashed line represents the sum of RMF potential energy and the centrifugal barrier energy for the proton resonant state $1f_{7/2}$. It also shows the energy spectrum of some proton single particle states including the resonant state $1f_{7/2}$.

It may be emphasized that besides the resonant state $1f_{7/2}$, other positive energy proton single particle states do not play any significant role in contributing to the total pairing energy as only this state has substantial overlap with the bound states near the Fermi level. This can be inferred from Fig. 2 wherein we have displayed the radial wave functions of some of the proton single particle states close to the Fermi surface, the proton Fermi energy being λ_p = 0.80 MeV.

The wave function for the $1f_{7/2}$ state plotted in Fig. 2 is clearly seen to be confined within a radial range of about 7 fm and has a decaying component outside this region, characterizing a resonant state. In contrast, the

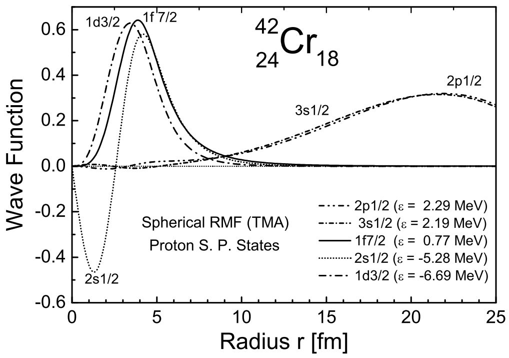

FIG. 2: Radial wave functions of a few representative proton single particle states with energy close to the Fermi surface for the nucleus $^{42}_{24}Cr_{18}$. The proton Fermi energy is located at $\lambda_p = 0.80$ MeV. In addition to the bound $1d_{3/2}$ and $2s_{1/2}$ states, the figure shows the resonant state $1f_{7/2}$.

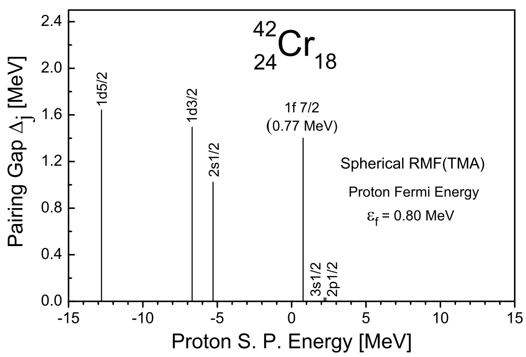

FIG. 3: Pairing gap energy Δ_j of proton single particle states with energy close to the Fermi surface for the nucleus $^{42}_{32}Cr_{18}$. The proton resonant single particle state $1f_{7/2}$ at energy 0.77 MeV has the gap energy of about 1 MeV which is close to that of bound states $1d_{5/2}$, $1d_{3/2}$ and $2s_{1/2}$.

main part of the wave function for the non-resonant states, e.g. $2p_{1/2}$ and $3s_{1/2}$, is seen to be spread over outside the potential region, though a small part is also contained inside the potential range. This type of states thus has a poorer overlap with the bound states near the Fermi surface leading to small value for the pairing gap Δ_j.

This is also clearly evident from Fig. 3 which shows the calculated single particle pairing gap energy Δ_j for some of the proton single particle states in the nucleus $^{42}_{24}Cr_{18}$. One observes indeed in Fig. 3 that the proton resonant single particle state $1f_{7/2}$ at energy 0.77 MeV has the pairing gap energy of about 1 MeV which is close to that of the bound states $1d_{5/2}$, $1d_{3/2}$ and $2s_{1/2}$. Also, Fig. 3 shows that the pairing gap value for the non-resonant states $2p_{1/2}$ and $3s_{1/2}$ lying in the continuum is negligibly small.

From the characteristics of the proton resonant $1f_{7/2}$ single particle state, it is evidently clear that this state behaves similar to a bound state. This property enables the nucleus $^{42}_{24}Cr_{18}$ to have finite life time even with negative two-proton separation energy while lying beyond the two-proton drip-line. It would be interesting to have this prediction verified experimentally.

Acknowledgments

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