Relativistic mean field theory for deformed nuclei with pairing

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It is our strong desire to treat all the nuclei including the unstable ones from the proton drip line to the neutron drip line. For a suitable description of finite nuclei, we have to include the deformation and the pairing correlations simultaneously. There is an extended study of all the even-even nuclei in the entire mass region by Hirata et al. including only the deformation [1]. This calculation provides a good account of all the nuclei and indicate that almost all nuclei except some with traditional magic numbers are deformed. This calculation, however, does not include the pairing correlations, since the conventional BCS treatment with the constant interaction is not able to handle the case where the Fermi surface is close to the unbound threshold [1].

Recently, there was an interesting suggestion made by Yadav et al. that the use of the delta function interaction in the BCS formalism with a proper introduction of the box boundary condition can provide a good description of the proton magic nuclei [2]. The applicability and justification of using such a delta function interaction has been discussed extensively in [3] and references therein. It is very interesting, therefore, to apply this prescription to deformed nuclei. In the present work, we take the expansion method of Gambhir et al.[4] for the mean field part and replace the BCS part with the constant interaction and the pairing window by the one with the delta function interaction. A detailed description of the present RMF+BCS model for deformed nuclei can be found in Ref. [5].

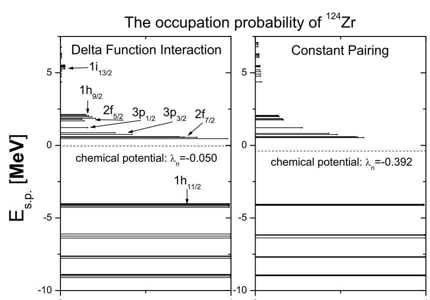

Figure 1: The occupation probability is shown by solid horizontal bar for each neutron single particle state in ^{124}Zr. The left panel is the result of the BCS calculation with the delta function interaction, while the right panel is the result of constant pairing calculation. The dotted horizontal line represents the Fermi energy. In both panels, the occupation probabilities of the continuum states are multiplied by a factor of 5 for guiding the eyes.

One interesting feature of exotic nuclei is the contribution from the continuum due to the pairing correlations. In this context, it is definitely very interesting to see how different the contributions from the continuum between the calculations with constant pairing interaction and the calculations with delta function interaction are. In Fig. 1, it is clearly seen that the BCS calculation with the delta function interaction can pick up more the continuum state whose wave function are concentrated in the nuclear region. The vacancy between $E = 2$ MeV and $E = 5$ MeV can be interpreted as an advantage of expansion method. We hope to study nuclei throughout the periodic table with the method we developed here. In the following, some results of our recent calculations are shown.

Figure 2: Correlation of the proton skin thickness $(r_p - r_n)$ as a function of the difference between the proton and neutron separation energy $(S_p - S_n)$.

In Fig. 2, the experimental results for recently observed neutron skin in Na isotope and proton skin in Ar isotope are reproduced quite well by our calculations except for ^{37}Ar and ^{38}Ar which can be attributed to possible existence of nuclear cluster. We have calculated the odd-Z proton emitters from $Z = 55$ to $Z = 73$. Here, we show some results for Lu and Ta isotopes in Fig. 3. The Comparison with experiment is quite good except for the odd-odd nuclei, ^{156}Ta and ^{150}Lu, where neutron-proton residual pairing interaction could play a role.

Figure 3: Single proton separation energies for Lu and Ta isotopes at and beyond the proton drip line, including results of RMF+BCS with NL3 parameter set (squares), results of RMF+BCS with TMA parameter set (points), predictions of RHB calculations (up triangle) and available experimental values (down triangle). The experimental values correspond to the negative values of the ground-state transition energies E_p

In conclusion, we have developed a self-consistent RMF+BCS method with delta function interaction in the pairing channel for deformed nuclei. An extensive study of all nuclei throughout the periodic table with the present approach is under way.

References

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