Weakly Bound Structures in Neutron Rich Si Isotopes

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Production of radioactive beams have facilitated the nuclear structure studies away from the line of β-stability, especially for the neutron rich drip line nuclei. Theoretical investigations of these nuclei have been carried out by using various approaches viz. few body model or clusters, shell model and mean field theories, both nonrelativistic as well as relativistic mean field (RMF) [1–3]. The advantage of the RMF approach, however, is that in this treatment the spin-orbit interaction is included in a natural way. This is especially advantageous for the description of drip-line nuclei for which the spin-orbit interaction plays an important role. In this communication we report briefly the results of our calculations for the Si isotopes [4] carried out within the framework of RMF+BCS approach.

It is found that for some of the neutron rich Si isotopes, in the vicinity of neutron drip-line, further addition of neutrons causes a rapid increase in the neutron rms radius with a very small increase in the binding energy, indicating thereby the occurrence of weakly bound structures in Si isotopes.

In Fig.1 we have shown the variation of rms radii of neutron (r_n) and proton (r_p) distributions obtained in our RMF+BCS calculations for Si isotopes as a function of increasing neutron number N. We have also shown the $r_0N^{1/3}$ variation by solid line for the purpose of comparison, where r_0 has been chosen to provide the best fit to the calculated results. It is evident from the figure that there occurs a sudden increase in the neutron rms radius at N=30 (this corresponds to ^{44}Si nucleus). The calculated radii are found to be in agreement

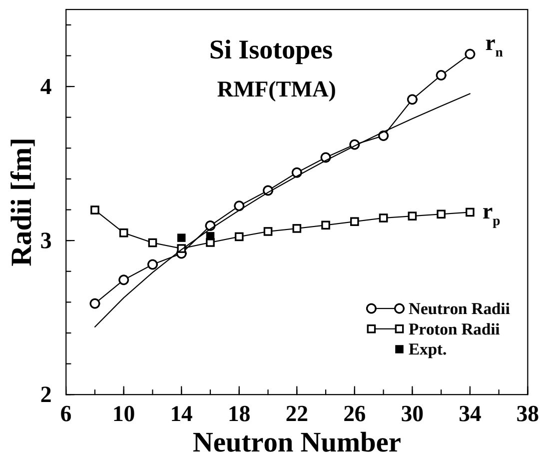

FIG. 1: Variation in the rms radii of neutron and proton distributions obtained in our RMF+BCS calculations for Si isotopes as a function of increasing neutron number N along with the available experimental data [5]. For the purpose of comparison of the neutron radii the solid line shows the $r_0N^{1/3}$ variation, where r_0 has been chosen to provide the best fit to the calculated results.

with the available measurements [5].

For weakly bound neutron rich nuclei the two neutron separation energy is rather small. In order to demonstrate this we have shown the results of two neutron separation energy for the entire chain of Si isotopes up to the neutron drip-line in the upper panel of Fig.2. It is seen that for Si isotopes with N = 30 - 34, the two neutron separation energy S_{2n} indeed tends to be very small.

These small values of separation energies can be understood by inspecting the variation in the position of the single particle states and that of the Fermi energy with increasing neutron number as depicted in the lower panel of

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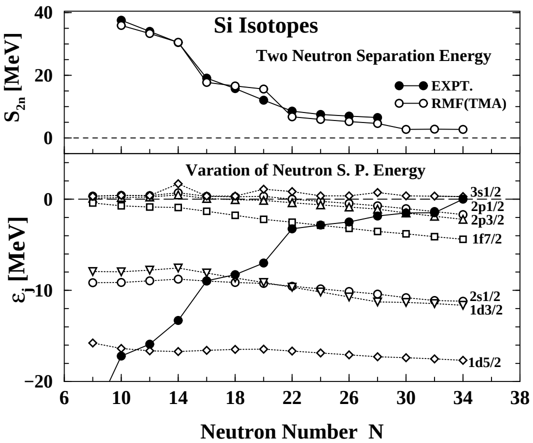

FIG. 2: RMF+BCS results for the Si isotopes showing the neutron number N dependence of the(i) two neutron separation energy and its comparison with the available experimental data [6] (upper panel), and (ii) relevant neutron single particle energy spectrum along with the position of neutron Fermi energy depicted by solid circles and connected by solid line (lower panel).

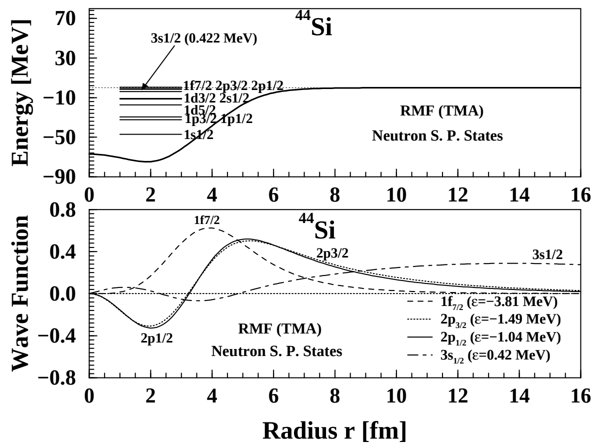

FIG. 3: Upper panel: The RMF potential energy (sum of the scalar and vector potentials), for the nucleus ^{44}Si as a function of radius is shown by the solid line. Lower panel: Radial wave functions of a few representative proton single particle states with energy close to the Fermi surface for the nucleus ^{44}Si.

Fig.2. Last neutrons in $^{44-48}$Si isotopes fill in the single particle states $2p_{3/2}$ and $2p_{1/2}$ which lie close to the Fermi level near the continuum threshold. Just above these two states lies the $3s_{1/2}$ state which remains in the continuum and does not come down to be bound even if further neutrons are added beyond N=34.

In order to illustrate the physical situation of neutron rich Si isotopes, we have plotted, in Fig.3, the RMF potential (upper panel), and radial wavefunction of some of the neutron single particle states close to the Fermi surface (lower panel) for the nucleus ^{44}Si. The upper panel also shows the spectrum for the neutron bound single particle states, and a positive energy state in the continuum. It is evident that the wave functions of the last neutrons, which occupy the low angular momentum single particle states $2p_{3/2}$ and $2p_{1/2}$ with small centrifugal barrier have considerable spread outside the potential region. Thus these states contribute substantially to the neutron density distribution at large distances. Due to this reason, for $^{44-48}$Si isotopes, the neutron density distribution has large tail. The gradual filling in of the neutron single particle states $2p_{3/2}$ and $2p_{1/2}$ with increasing neutron number causes the weakly bound structures in the $^{44-48}$Si isotopes.

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