Chapter 8

Conclusions and Future Prospects

8.1 Conclusions

In the present work, we have performed large scale shell model calculations on neutron rich nuclei for three different regions of nuclear chart viz. *sd*, *fp*, and *fpg* to answer the question of what happens with the nuclear shell structure when we move out of the valley of β-stabilitiy. The modern large-scale shell-model calculations give at present the most accurate and comprehensive description of nuclei including those at very neutron-rich or very proton-rich edges. It can not only predict low-lying energy levels but can also sucessfully make most important theoretical predictions for comparison with the experimental findings.

We have studied neutron rich oxygen and fluorine isotopes in the framework of nuclear shell model for *sd* model space using four different types of effective interactions. For diagonalization of matrices shell model code Oxbash and Nushell are used. $E(2^+)$ excitation energies are calculated and compared with recent available data. Shell closure at N=16 is shown and B(E2) values and quadrupole moments are also reported. Proton monopole shift of neutron rich fluorine isotopes are also studied and it is observed that as more and more neutrons are added the effective proton single-particle energies of $d_{5/2}$, $s_{1/2}$ and $d_{3/2}$ levels get changed. Monopole shift in the proton states in odd neutron-rich F isotopes have been studied with neutron number changing from N = 10 to 20 for four different interactions. The variation of monopole shift points out towards appearance of shell closure at N = 14 and its disappearance at N = 16. Low lying states of odd F isotopes have also been calculated in the limited configuration space of *sd* shells for these interactions.

Recently measured experimental data of Legnaro National Laboratories on neutron rich even isotopes of $^{62-66}$Fe with A=62, 64, 66 have been interpreted in the framework of large scale shell model. Calculations have been performed with a newly derived effective interaction GXPF1A in full *fp* space without truncation. The experimental data is very well explained for ^{62}Fe, satisfactorily reproduced for ^{64}Fe and poorly fitted for ^{66}Fe. The increasing collectivity reflected in experimental data when approaching N=40 is not reproduced in calculated values. This indicates that whereas the considered valence space is adequate for ^{62}Fe, inclusion of higher orbits from *sdg* shell is required for describing ^{66}Fe. In the second part large scale shell model calculations have been performed to calculate the negative parity states of even-odd $^{61-65}$Fe isotopes. The results are compared with the recent experimental data reported at Legnaro National Laboratories and also with earlier calculations with *fpg* interaction in a truncated configuration space. It is observed that negative parity states of ^{61}Fe can be well reproduced with GXPF1A interaction in full *fp* space without truncation. For ^{63}Fe the correct ordering of levels is not reproduced. The structure of the wave function for the ground state and the first excited state suggest that the ordering of the single particle energy levels gets modified due to monopole correction.

The large scale shell model calculations have been carried out for odd-odd $^{58-62}$Mn isotopes in two different model spaces. First set of calculations have been carried out in full *fp* shell valence space with two recently derived *fp* shell interactions namely GXPF1A and KB3G treating ^{40}Ca as core. The second set of calculations have been performed in *fpg* valence space with the *fpg* interaction treating ^{48}Ca as core and imposing truncation on the number of valence particles. Correct ordering of ground state and the first excited state levels for ^{58}Mn is predicted only with *fpg* interaction showing the importance of $0g_{9/2}$ orbital in the valence space for this nucleus. None of the interactions could predict the correct ordering of levels for ^{62}Mn. Experimental data on ^{62}Mn is sparse. More experimental data and location of negative parity states is needed to ascertain the importance of $0g_{9/2}$ and higher orbitals in interpreting the experimental data.

Low-lying states of Ni, Cu and Zn isotopes for $40 \leq N \leq 50$ have been calculated for two recently available interaction by Nowacki and Lisetskiy using ^{56}Ni as a core, the Hamiltonian have been diagonalized using m-scheme code ANTOINE at SGI-cluster computer at GANIL. The B(E2) values are also discussed.

The results obtained for neutron rich Cu, Ni and Zn isotopes taking ^{56}Ni as core are unsatisfactory viz. large E(2^+) value for very neutron rich nuclei, small B(E2) values in comparison to experimental values and for ^{75}Cu, ^{77}Cu and ^{79}Cu the ground state is $3/2^-$ instead of experimental indication of $5/2^-$. In view of this large scale shell model calculations have been performed for neutron rich nickel, copper and zinc isotopes with $40 \leq N \leq 50$ using ^{40}Ca as a core by including the $f_{7/2}$ orbit. There is earlier version of effective interaction for ^{40}Ca by Sorlin *et al* , but the effective proton single-particle energy for Sc isotopes using this interaction is not correctly reproduced for more neutron rich nuclei. In the present work 28 two body matrix elements of the earlier interaction between $0f_{5/2}0g_{9/2}$ and $0f_{5/2}0g_{9/2}$ states have been renormalized and tuned such that the agreement with the experimental data improves.

8.2 Future Prospects

Today research on nuclear physics focuses on exploring nucleonic matter under extreme conditions such as those that can be created in modern accelerator laboratories. The opportunities offered by beams of exotic nuclei for research in the areas of nuclear structure physics and nuclear astrophysics are exciting and world-wide activity in the construction of different types of radioactive beam facilities bears witness to the strong scientific interest in the physics that can be probed with such beams. Nuclei far from stability allow us to amplify and isolate particular aspects of the nuclear interaction and dynamics. Future work will involve, for example, mapping the neutron drip line further up, investigating neutron halo systems, learning about the astrophysical *rp*- and *r*-process paths, exploring the evolution of shell structure and neutron skins, creating further super heavy nuclei, studying super-allowed beta-decay in very light proton rich nuclei, developing a deeper understanding of proton-neutron pairing and studying the exotic phenomenon of proton radioactivity.

The actual mechanism which causes the changes in nuclear structure as neutron number increases in a nuclear system is still an open question. The present work can be extended to the study of following aspects:

1. the role of $d_{5/2}$ orbital from *sdg* shell in the evolution of shell structure towards ^{78}Ni.
2. the role of tensor part of the proton-neutron interaction, especially between the proton *fp* and neutron $g_{9/2}$ orbital.

3. the role of particle-hole excitations through Z=28 and N=40 shell gaps for the onset of deformation below and above ^{68}Ni.

4. shell evolution around the ^{100}Sn and ^{132}Sn doubly magic nuclei. Further to study the structure of Sn isotopes above ^{132}Sn and new shell closure at ^{140}Sn in the context of r-process.

5. the role of shell structures and deformation in Pb region.