pfg9a - New effective interaction for $fpg_{9/2}$ space

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The nickel isotopes ($Z = 28$) cover three doubly-closed shells with number $N = 28$, $N = 40$, $N = 50$ and therefore a unique testing ground to investigate the evolution of shell structure. The ^{68}Ni and its neighboring attracted the interest of recent research to answer the magicity versus superfluidity question related to doubly magic character of this nuclei. For the copper isotopes, the important question is related to rapid reduction in the energy of $5/2^-$ state as the filling of neutrons started in the $\nu g_{9/2}$ orbital . In the Cu isotopes as $N \sim 40$, the state reveal three types of structures – single-particle, collective or coupling of single proton with neighboring even Ni isotopes. In the Zn isotopes with two protons more than the semi-magic $Z = 28$ nickel nuclei, the spherical $N = 40$ gap may not be strong enough to stabilize the nuclei in spherical shape when protons are added to the ^{68}Ni core. Thus $B(E2)$ value is larger in the chain of Zn isotopes. To understand the evolution of nuclear structure, the importance of monopole term from the tensor force is pointed out by Otsuka *et al.*

The experimental $E(2_1^+)$ for $Z = 28$ to $Z = 36$ are shown in Fig. 1. In this figure $E(2_1^+)$ states in Zn are overall lower compared to Ni and an additional decrease of the $E(2_1^+)$ energy in Zn isotopes is obtained between N=40-50 compared to N=28-40. This figure also reveal the enhancement of collectivity beyond $Z = 30$, because of rapid decrease of $E(2^+)$. Below the Ni chain, the spectroscopy of Cr, Fe isotopes shown an increased collectivity toward $N = 40$, revealing the collapse of this shell closure.

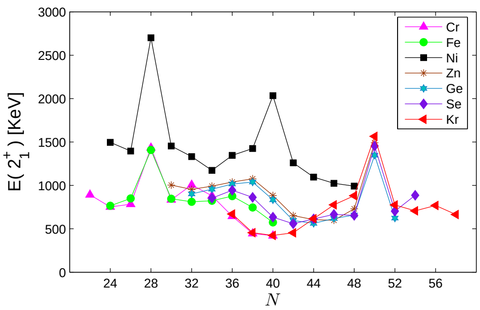

FIG. 1: Systematic of the experimentally observed $E(2_1^+)$ for $Z = 28$ to $Z = 36$ near the $N = 28$, 40 and 50 shell closure.

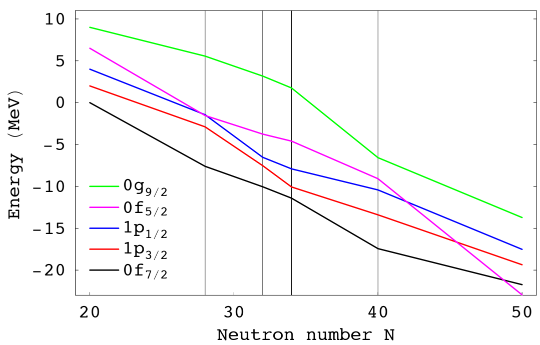

FIG. 2: Effective single-particle energies in $^{41-71}$Sc isotopes using *pfg9* interaction.

Shell model calculations for Ni, Cu and Zn isotopes by modifying *fpg* interaction due to Sorlin *et. al.*, [Phys. Rev. Lett. 88, 092501 (2002)] have been reported. In the present work 28 two body matrix elements of the earlier interaction have been modified. Present interaction is able to explain new experimental results for this region.

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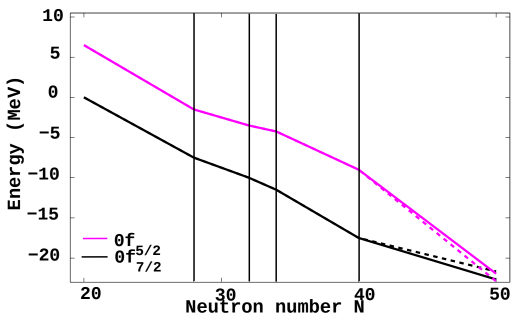

FIG. 3: Effective single-particle energies in $^{41-71}$Sc isotopes using *pfg9a* interaction. In this figure, the results for $pfg9$ interaction are also shown as dotted lines.

As more and more neutrons are added in $g_{9/2}$ orbital, $f_{7/2}$ orbital becomes more repulsive and $f_{5/2}$ more attractive. Thus proton $f_{5/2}$ is pulled down while $f_{7/2}$ is lifted up, as N increases, this is due to monopole interaction produced by tensor force between a proton in $j_{>,<} = l \pm 1/2$ and a neutron in $j'_{>,<} = l' \pm 1/2$. Effects on $p_{3/2}$ and $p_{1/2}$ orbitals are small and can be neglected. For the original fpg interaction, $f_{5/2}$ level crosses the $f_{7/2}$ at ^{70}Sc and become lower in energy. This appears to be unrealistic. In the present work, we have modified $g_{9/2}f_{7/2}$ and $g_{9/2}f_{5/2}$ matrix elements. This modified interaction is named as *pfg9a*. The effective single-particle energies for $^{41-71}$Sc isotopes are shown in Figs. 2 and 3 for original and modified interaction respectively.

In summary, the existing $pfg9$ interaction for $fpg_{9/2}$ space with ^{40}Ca core has been modified by changing $\pi f_{5/2}\nu g_{9/2}$ and $\pi f_{7/2}\nu g_{9/2}$ matrix elements [1, 2]. The new interaction is named as $pfg9a$ has been tuned for Cu isotopes and tested for Ni and Zn isotopes. The $pfg9a$ interaction give 0^+ ground state in an even-even nucleus like in Ni and Zn isotopes which is the characteristic of any reasonable interaction. These results indicate that further modification in interaction and even inclusion of $1d_{5/2}$ orbit is important in the shell model calculations. The modification of Sorlin *et. al.,* interaction is also attempted in[3], but it will be remain to test this interaction is universal or not for this region. An attempt by including $1d_{5/2}$ orbit in $fpg_{9/2}$ space to explain collectivity for fp shell nuclei is recently reported in [4].

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