A Study on Pairing Correlation in Ni Isotopes

Nicemon Thomas,* Anjana A. V and Antony Joseph

Department of Physics, University of Calicut, Kerala, 673635

**email: nmtvattoth@gmail.com*

Introduction

Pairing correlations play a vital role in deciding the structure of most of the finite and infinite nuclear systems. The effect of pairing correlations are extensively studied along the dripline nuclei and has been proved that it contribute additional binding and thereby increased stability and also influence β decays such as neutrinoless double β decay, odd- even staggering, incompressibility, symmetry energy, moments of inertia, alignments, deformation etc. For nuclei with $N > Z$, neutron (nn) and proton (pp) are known to exist, with zero angular momentum (J) and isospin $(T) = 1$. For those nuclei with $N \approx Z$, nucleons near the Fermi surface tend to occupy identical orbitals, leading to neutron- proton (np) coupling, with either $J = 0$ and $T = 1$ (isovector) or $J = 1$ and $T = 0$ (isoscalar) pairs. [1]

Solving many- body problems in physics is rather challenging. The nature of the nuclear force and the relationship between nucleon-nucleon interaction and single particle forces is still masked. Bohr, Mottelson and Pines proposed the analogy of BCS theory in superconductors to that of nucleus. It is evident that very simple pairing interactions lead to BCS approximation, which gives results in agreement to experimental values. For nuclei far from stability line BCS theory falls inadequate; for we need to incorporate single particle states describing the influence of pairing upon unstable states. It is at this point that we opt for Hartree-Fock-Bogoliubov (HFB) theory, which describes single particle states with pairing interaction.

In the present study we made an attempt to understand the effect of nucleon pairing and estimated the neutron and proton pairing gaps in the case of Nickel isotopes in the mass range 44- 82 covering two doubly magic configurations. For this we performed the Hartree- Fock- Bogoliubov + Harmonic oscillator (HFB- HO) calculations, imposing no reflection symmetries for the purpose. The Skyrme functional used here is UNE0.

Formalism

HFB equation in co-ordinate representation appropriately solves asymptotic part of nucleonic density, generally for the treatment of spherical nuclei. For non- equilibrium shapes, to implement deformation into co-ordinate space HFB equation, we employ, (a) two basis method, which works by diagonalizing nucleon- nucleon part of the HFB Hamiltonian. (b) canonical HFB method, which uses eigen states of one body density matrix and (c) Basis- spline axial co-ordinate space HFB method. [2] Since it has been found that these modes of HFB solutions are not fast converging, we expand quasiparticle HFB wave functions in a complete set of transformed harmonic oscillator (THO) basis. However the variational minimization to define the basis parameters will be time consuming, which makes it inappropriate to apply to all nuclei. The new method of choosing THO basis requires no variational optimization, instead the results of HFB+HO calculation is given as input. [2]

The HFB equations could be written as

$$\begin{bmatrix} e + \Gamma - \lambda & \Delta \\ -\Delta^* & (e + \Gamma)^* + \lambda \end{bmatrix} \binom{U}{V} = E\binom{U}{V} \quad (1)$$

where λ is the Lagrange multiplier for fixing average particle number. The program iteratively diagonalizes the nucleon- nucleon part of the HFB Hamiltonian in each step

using the Skryme forces and restoring particle number symmetry using Lipkin-Nogami method, which analogously acts the role of Lagrange multiplier.

The pairing interaction used in the HFBTHO approach is of zero- range having the form,

$$V_{pair}(r,r') = V_0(1-\eta\frac{\rho(r)}{\rho_0})\delta(r,r') \qquad (2),$$

where V_0 is the pairing strength and $\rho(r)$ is the isoscalar nucleonic density and $\rho_0 = 0.16fm^{-3}$. The density dependence of pairing interaction could be varied by adjusting the value of η. If, $\eta = 1$,it will be called surface interaction, with pure density dependence and if $\eta = 0$, it will not have any density dependence, called volume interaction. Also if we set $\eta = 0.5$, it will be known as mixed pairing with average effects of both surface and volume interactions.

Results and conclusion

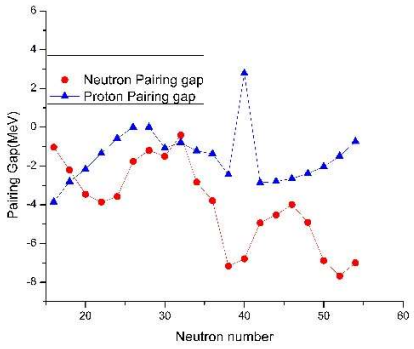

Fig. 1. .Variation of pairing gap for both protons and neutrons with Neutron number for various isotopes of Ni.

We have plotted the pairing gaps of various isotopes of Nickel with neutron number ranging from 16 to 54.

In earlier studies [4,5], it has been reported that ^{78}Ni is having the doubly magic configuration. We have evaluated, by the method described above, the pairing gap for protons and neutrons for a series of even-even Ni isotopes. It is given in Fig 1. We have observed an oscillatory nature for this in the case of both neutrons and protons. We have also evaluated the Fermi energies for both protons and neutrons in these mass range. It has been noticed that for Ni isotopes in the mass range 44-82, the neutron Fermi energy increased from -22.746 MeV to -3.199 MeV and the corresponding proton pairing energy decreased from 2.483 MeV to -20.112 MeV. Neither for ^{56}Ni nor for ^{78}Ni, no sudden change in the Fermi energy values have been noticed. More elaborate study in this regard needs to be conducted to further evaluate the influences of pairing effects on other characteristics of Ni isotopes.

References

[1] S. Frauendorf et al., Progress in Particle and Nuclear Physics 78(2014) 24-90.

[2] M.V. Stoitsov et al., Computer Physics Communications 167 (2005).

[3] M.V. Stoitsov et al., Computer Physics Communications 184 (2013) 1592–1604.

[4] L. Olivier et al., Physical Review Letters, 119 (2017) 192501

[5] A Welker et al., Physical Review Letters, 119 (2017) 192502