Study of neutron-proton pairing correlation for $N = Z$ ^{72}Kr, ^{76}Sr, and ^{80}Zr nuclei.

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The mass region $A = 80$ is known to provide a wide variety of nuclear structure phenomena that are quite unique to this region. Rapid changes of shape have been observed, both with varying neutron and proton number and with rotational frequency [1]. The stongest motivation of studying $N = Z$ nuclei is that both protons and neutrons occupy identical single particle orbitals. The simultaneous filling of orbitals is predicted to result in a significant enhancement of neutron-proton (np) pairing correlations [2] with respect to the more established like-nucleon (nn and pp) pairing modes. By the Pauli's exclusion principle, in like nucleon pairing, the nucleons can only form $J = 0, T = 1$ (isovector) pairs. However, this constraint is removed for np pairing, where the nucleons can also couple together to form $J = 1, T = 0$ (isoscalar) pairs. Thus $N = Z$ nuclei provide an excellent laboratories to investigate various physical phenomenas like shape co-existence, prolate-oblate mixing or shape transitions, delayed rotational alignment etc.

The purpose of the present work is to study the effects of neutron-proton pairing correlation in spontaneous breakdown of rotational symmetry in $N = Z$ ^{72}Kr, ^{76}Sr and ^{80}Zr nuclei. We have adopted Variational Mean Field Theory based on Hartree-Fock-Bogoliubov framework. In the present calculations, we have employed the valence space spanned by $1p_{1/2}$, $1p_{3/2}$, $0f_{5/2}$ and $0g_{9/2}$ orbits for protons and neutrons under the assumption of $N = Z = 28$ sub-shell closure. The single-particle energies employed are (in MeV): $1p_{3/2} = 0.0$, $0f_{5/2} = 0.78$, $1p_{1/2} = 1.08$ and $0g_{9/2} = 3.5$. We have adopted the monopole corrected two-body effective interaction [3] for $0f1p0g$ shell orbits with $T = 1$ and $T = 0$.

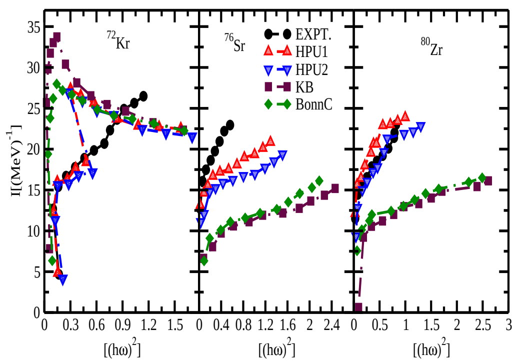

FIG. 1: The moment of inertia $\mathcal{I}$ as a function of square of angular frequency $(\hbar\omega)^2$ for ^{72}Kr, ^{76}Sr and ^{80}Zr nuclei with neutron-proton (np) pairing interaction. Here on the x axis the factor h = $\hbar$.

We start with the effective mean-field Hamiltonian written in terms of two-body matrix element of effective interaction as:

$$H = \sum_{\alpha} \epsilon_{\alpha} a^{\dagger}_{\alpha} a_{\alpha} + \frac{1}{2} \sum_{\alpha\beta} \langle \alpha\beta \mid V_{\mu\mu} \mid \alpha\beta \rangle a^{\dagger}_{\alpha} a^{\dagger}_{\beta} a_{\alpha} a_{\beta}, \quad (1)$$

The wave functions of a state with definite value of the total angular momentum J is written as,

$$\mid \Psi^{J}_{K=0} >= \acute{N} \int d\Omega d^{J}_{00} exp \left(\sum_{\alpha\beta} F_{\alpha\beta}(\theta) a^{\dagger}_{\alpha} a^{\dagger}_{\beta} \right) \mid 0 >, \quad (2)$$

TABLE I: Self consistent computed HFB energy E_{HFB} and intrinsic quadrupole moment $< Q_o^2 >$ with neutron-proton (np) pairing interaction for $N = Z$ Kr, Sr and Zr nuclei

Nuclei	INT	Kr		Sr		Zr	
		E_{HFB}	$< Q_o^2 >_{HFB}$	E_{HFB}	$< Q_o^2 >_{HFB}$	E_{HFB}	$< Q_o^2 >_{HFB}$
N=Z	KB	31.29	27.22	51.91	23.29	79.32	35.21
	BonnC	43.67	37.31	62.32	34.12	83.31	36.19
	HPU1	35.87	23.53	55.32	21.54	79.34	28.21
	HPU2	46.41	35.94	64.10	33.65	87.62	36.42

The reduced electric quadrupole transition probabilities, $B(E2; J \rightarrow J-2)$ between the yrast states belonging to two different angular momentum states are calculated as,

$$B(E2; J_i \rightarrow J_f) = \left(\frac{2J_f+1}{2J_i+1}\right)| \left\langle \Psi^{J_f}(\beta)||Q_0^2||\Psi^{J_i}(\beta)\right\rangle|^2. \quad (3)$$

The new interaction reproduce well the experimental data of rotational energy spectrum, moment of inertia, E2 transition probabilities and quadrupole moments of these nuclei. It is noticed from Table I that the values of E_{HFB} and $< Q_o^2 >_{HFB}$ are increasing on the monopole correction included in two- body matrix elements of the realistic effective interactions. On comparing our results with ref.[3] , we observe that with inclusion of np pairing interaction the values of E_{HFB} and $< Q_o^2 >_{HFB}$ increases substancially for the "KB" and "BonnC" realistic interaction. Whereas, these values are quite close for the monopole corrected new effective interaction "HPU1" and "HPU2". We observe that low yrast energies of ^{72}Kr with "KB" and "BonnC" effective interaction lead to sharp increase in moment of inertia till $J = 10\hbar$ state and then a sudden decrease at higher spins. Whereas, monopole corrected "HPU1" and "HPU2" effective interaction with np pairing correlation lead to sharp backbend for ^{72}Kr at $J = 14\hbar$ state as compared to smooth curve with a slight upbend indicated around $\hbar\omega = 0.8$ MeV for "HPU1" effective interaction without np pairing correlation [3]. This result with np pairing correlation is in contradiction with the smooth curve obtained experimentally [1]. The backbending observed in ^{72}Kr is due to the correlation between protons and neutrons within the $g_{9/2}$ shell. The backbending features are produced when a pair vanishes and anomalous rotational alignment takes place. The band crossing in ^{72}Kr nuclei may arise due to "2p-2h" excitations by n-p residual interaction. The np pair de-pairs in the presence of isoscalar np pairs ($T = 0$) first, then the de-pairing is continued in the presence of isovector np pairs ($T = 1$). The np- residual interaction has a physical origin that it contributes to the HF field and tends to renormalize the effective interaction which leads to band crossing in even-even nuclei. Since in ^{76}Sr nucleus, the interaction between the ground state and aligned bands is very large, so no abrupt irregularities in moment of inertia is observed with np pairing correlation. However, for ^{80}Zr, we obtain a slight upbend with np pairing correlation in higher angular momentum region. Whereas, without np pairing correlation ^{80}Zr ground state band is smooth to the highest frequency observed ref.[3]. This upbend in moment of inertia may arise due to proton pair breaking. In our calculation, it is shown that the "2p-2h" excitations by n-p residual interaction are the essential ingredients of the mean-field description of the occurence of backbending in ^{72}Kr.

References:

1) S. M. Fischer et al., Phys. Rev. Lett. **87**, 132501, (2001).

2) A. L. Goodman, Adv. Nucl. Phys. **11**, 263, (1979).

3) S. K. Dhiman and P. Roy *communicated*, (2010).