Deformed states in ^{35}Cl: A Shell model Description

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Recent observation of superdeformed (SD) states [1] in lighter mass nuclei in the *sd-pf* shell, like ^{40}Ca [2] and ^{36}Ar [3] has generated new interest. This region gives us a unique opportunity to investigate experimentally the interplay between single particle and collective degrees of freedom and interpret them theoretically from a microscopic point of view using large-scale shell model. The observed superdeformed bands in ^{36}Ar and ^{40}Ca are well explained by spherical shell model calculations and the configurations of these bands are $(sd)^{16}(pf)^4$ in ^{36}Ar and $(sd)^{12}(pf)^8$ in ^{40}Ca, respectively. However, till now no such band has been observed in odd-A isotopes in this mass region.

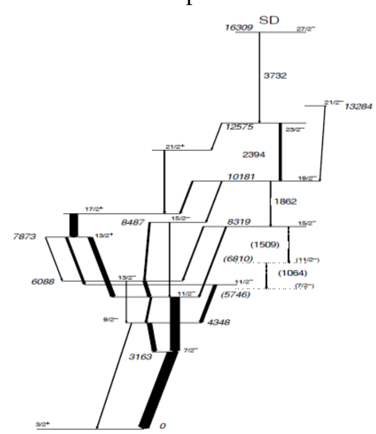

Fig. 1: Partial level scheme of ^{35}Cl.

Recently, we have proposed [4] a sequence of gamma rays in ^{35}Cl decaying from short-lived states manifested through their large Doppler shifts, to belong to a superdeformed band. Out of the observed seven shifted peaks, three E2 transitions (1862 keV, 2394 keV and 3732 keV) could be placed in the same band (Fig. 1). Lifetimes of the relevant states have been determined using centroid shift and lineshape analysis. The extracted B(E2) values are large (~30 W.u. corresponding to β~0.26). These values are consistent with the corresponding values for the SD bands in ^{36}Ar (β~0.45) [3] and ^{40}Ca (β~0.59) [2]. In this report we shall discuss the shell model description of this new SD band in ^{35}Cl.

Large basis shell model (LBSM) calculations have been done using the code OXBASH [5]. The valence space consists of full *sd-fp* orbitals for both protons and neutrons above the ^{16}O inert core. The *SDPF.SM* [3] and *SDPFMW* [6] Hamiltonians have been used in these calculations. The *SDPF.SM* interaction was originally devised for calculation in fixed $n\hbar\omega$ spaces and was successful in interpreting the SD band in ^{36}Ar [3]. The *SDPFMW* interaction was successfully used to interpret the low-lying states in ^{35}Cl [7].

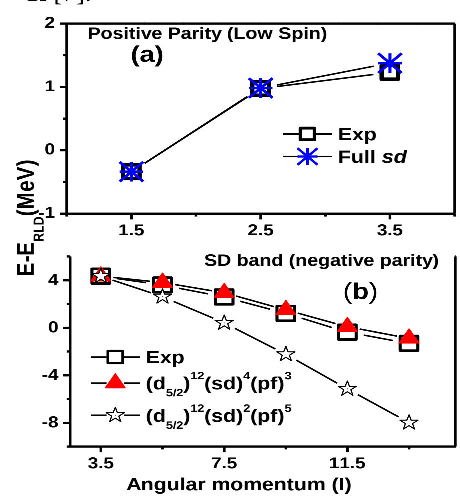

Fig-2: Excitation energy (E) relative to a rigid rotor energy E_{RLD} = 0.09004 I(I+1) in ^{35}Cl, as a function of spin for (a) low spin positive parity states and (b) observed superdeformed band.

The number of valence particles (protons + neutrons) in ^{35}Cl is 19. The energy spectra of ^{35}Cl have been calculated by exciting n = 0, 3 and 5 number of particles into *fp* shell. The low-lying positive parity states were reproduced well for n=0 particle excitation (Fig. 2a) within full *sd* space. However for n>1, untruncated calculations were impossible due to large dimensionality. In earlier studies, the superdeformed (SD) band in ^{36}Ar has been reproduced with 4p-4h excitation [3] within a truncated space assuming closed $1d_{5/2}$ orbitals.

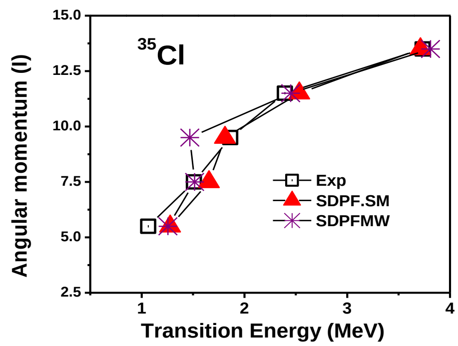

Fig. 3 Comparison between the experimental and theoretical gamma energies for the observed SD band in ^{35}Cl.

To start with, we reproduced the results for ^{36}Ar as per the prescriptions given in Ref [3]. Later similar calculations with n = 3 and 5 particle excitations for ^{35}Cl were performed with *SDPF.SM* only. It was found that spectra for n=3 particle excitation exhibited better agreement with the observed deformed band (Fig. 2b).

The two sets of results with n=3 for two interactions have been compared with experimental data in Fig. 3. Although gamma transitions from $15/2^-$ and $11/2^-$ states are not observed experimentally, we have shown them in the experimental diagrams (Figs. 1, 2b, 3) assuming rotational band spacing. The results with *SDPF.SM* interaction show better agreement with data. It was found that the wavefunctions of these states (n=3, *3ħω excitation*) have substantially larger configuration mixing compared to other states (n=1, *1ħω* excitation) with same angular momentum.

Shell model calculation for n = 4 *(4ħω excitation)* excitation in ^{35}Cl with these two interactions have also been done to check the possibility of presence of a SD band with positive parity. However, the transition energies predicted by these calculations do not show any regular correlation with their angular momenta indicating non-collective nature of these bands.

Theoretical reduced transition probabilities for E2 transitions (B(E2)) in this band have been calculated with effective charges e_p = 1.5e, e_n = 0.5e (Fig. 4). The calculated values agree reasonably well with the experimental B(E2)'s extracted from our lifetime data. These transition probabilities are substantially larger than those of the other transitions connecting states generated by single particle excitations indicating the collective nature of these states.

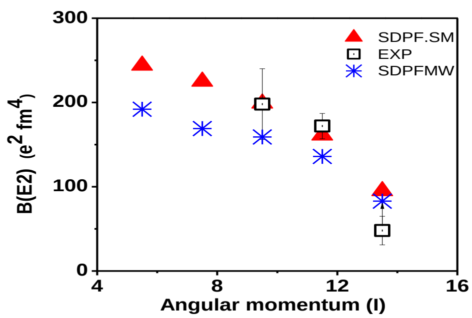

Fig. 4 B(E2) values for 3p-3h calculation of the observed super deformed band in ^{35}Cl.

To summarize, LBSM calculations have been done to understand the origin of super deformed band in ^{35}Cl. This band has a multi-particle multi-hole (*3p-3h*) structure indicated by $(sd)^{16}(pf)^{3}$ configuration. Experimental results were reproduced with *SDPF.SM*. Large configuration mixing and large B(E2) values strongly justify the SD nature of the proposed band in ^{35}Cl.

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