Un-even transition strengths in A =35 mirror nuclei: A role of isospin mixing

Y. Sapkota[1], Abhijit Bisoi[1*] and S. Sarkar[1]
[1]Indian Institute of Engineering Science and Technology, Shibpur, Howrah - 711103, INDIA
* email: abijitbisoi@gmail.com

Introduction

Nuclei located on or close to the *N*=*Z* line have been generating a considerable interest during the last few years. This region gives us a unique opportunity to investigate some fundamental problems in nuclear physics like isospin symmetry of nuclear interaction. The isospin *T* is a good quantum number under the fundamental assumptions of charge symmetry and charge independence of the strong nuclear force. If isospin symmetry holds in nuclear interaction, then the level schemes and strength of *E*1 transitions between analog states of a mirror pair should be identical. Moreover, ΔT=0 *E*1 transitions are forbidden in *N*=*Z* self-conjugate nuclei by isospin selection rules. Therefore, isospin symmetry breaking effects can be studied by investigating the level structures of mirror or self-conjugate nuclei.

In sd shell region, a striking structural difference between the mirror pair ^{35}Cl-^{35}Ar has been found [1, 2]. Large mirror energy difference (MED) and un-even E1 transition strengths between these nuclei have been observed. The origin of this large MED observed in the mirror pair has been explained in terms of nuclear charge symmetry breaking multipole (BM), Coulomb multipole (CM) and Coulomb monopole effects (Cm) [1,2]. However, the different decay patterns from the 7/2$^-$ level is not yet justified. J. Ekman et. al., [1] suggest that these dramatic difference in decay patterns of the 7/2$^-$ states in the *A* = 35 mirror pair may be due to isospin mixing. However, they have not estimated the amount of mixing. We have investigated the structure of these levels both experimentally and theoretically. We have populated ^{35}Cl-^{35}Ar using INGA facility at IUAC, New Delhi. We have measured the mixing ratios (δ) for a few transitions in ^{35}Ar and from a simple two state mixing analysis, we have estimated the amount of isospin mixing for these levels of interest.

Experimental Observation

The level structure of ^{35}Cl-^{35}Ar up to spin 7/2$^-$ is shown in Fig-1. It has been observed that in ^{35}Cl, the 7/2$^-$ state decays to the 3/2$^+$ ground state by a strong 3163 keV (*M*2) transition and to the 5/2$^+$ first excited state through a weak 1400 keV (*E*1) transition. The 1763 keV (*M*1) transition from the 5/2$^+$ level is also weak. On the other hand, in ^{35}Ar, the corresponding transition strengths are opposite. The intensity of the decay out 3197 keV (*M*2) transition is very weak whereas 1446 keV (*E*1) and 1751 keV (*M*1) transitions are very strong. But from the consideration of goodness of isospin symmetry, these should be identical. Therefore, these contrasting decay patterns provide a strong evidence of isospin mixing in the states as pointed out by J.Ekman et. al. [1].

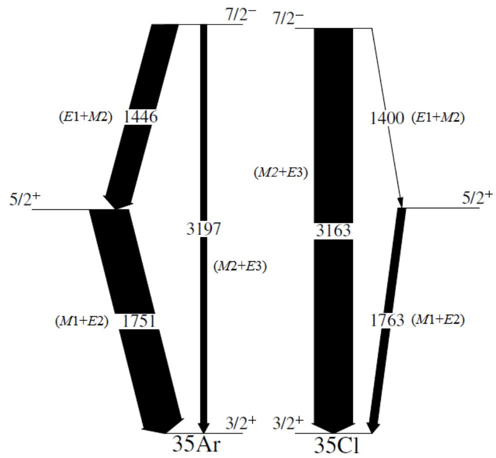

Fig-1: Decay structure of ^{35}Cl-^{35}Ar mirror pair from 7/2$^-$ excited state.

Two state mixing Calculation

In order to estimate the amount of isospin mixing, we have carried out a simple two state mixing calculation for these states of interest. In this model calculation, we have represented the wave function of 7/2$^-$ and 5/2$^+$ levels as a mixture of *T*=1/2 and *T*=3/2 as

$\Psi(7/2^-)=a_1\ |J=7/2^-,T=1/2> + b_1\ |J=7/2^-,T=3/2>$

and

$\Psi(5/2^+)=a_2\ |J=5/2^+,T=1/2> + b_2\ |J=5/2^+,T=3/2>$

where a and b are the mixing coefficients with $a^2+b^2=1$.

These two levels are connected by $E1+M2$ transition. Therefore, the reduced transition matrix elements for this transition can be written as

$$\langle 7/2^- | E1 | 5/2^+ \rangle = a1a2\langle \tfrac{7}{2}-,0.5|E1|\tfrac{5}{2}+,0.5\rangle + a1b2\langle \tfrac{7}{2}-,0.5|E1|\tfrac{5}{2}+,1.5\rangle + b1a2\langle \tfrac{7}{2}-,1.5|E1|\tfrac{5}{2}+,0.5\rangle + b1b2\langle \tfrac{7}{2}-,1.5|E1|\tfrac{5}{2}+,1.5\rangle$$ for E1 transition and

$$\langle 7/2^- | M2 | 5/2^+ \rangle = a1a2\langle \tfrac{7}{2}-,0.5|M2|\tfrac{5}{2}+,0.5\rangle + a1b2\langle \tfrac{7}{2}-,0.5|M2|\tfrac{5}{2}+,1.5\rangle + b1a2\langle \tfrac{7}{2}-,1.5|M2|\tfrac{5}{2}+,0.5\rangle + b1b2\langle \tfrac{7}{2}-,1.5|M2|\tfrac{5}{2}+,1.5\rangle$$ for M2 transition

One can now estimate these mixing coefficients from transition strengths *or* multipole mixing ratios (δ) where $\delta = \text{const.}\dfrac{\langle 7/2^- | M2 | 5/2^+ \rangle}{\langle 7/2^- | E1 | 5/2^+ \rangle}$. For $E1$ transition this constant $=0.921\text{X}10^{-4}\, E_\gamma$, where E_γ is in MeV. The transition matrix elements for $M1+E2$ ($5/2^+ \rightarrow 3/2^+$) and $M2+E3$ ($7/2^- \rightarrow 3/2^+$) transitions are also represented in the same manner.

In this present work, we have estimated the mixing coefficients (a, b) from the experimental multipole mixing values for $E1$, $M1$ and $M2$ transitions and have verified our results with their transition strengths wherever available. In ^{35}Ar, we have considered the mixing ratios (δ) measured from our last INGA experiment at IUAC [3]. However, transition strengths were not measured due to low statistics of the experimental data. For ^{35}Cl, the mixing ratios (δ) and the transitions strengths are taken from NNDC [4]. The transition matrix elements for pure ΔT=0 and ΔT=1 transitions in the right hand side of the above equation are taken from shell model calculations. Large basis shell model calculations for ^{35}Cl-^{35}Ar have been performed using the code OXBASH [5]. The number of valence particles (protons + neutrons) in ^{35}Cl-^{35}Ar are 19. The *sdpf* model space and the *sdpfmw* [6] interaction were used for the calculations.

Results and discussion

The $3/2^+$ ground state is a pure T=1/2 state and based on this, we have estimated the mixing coefficients a_2 and b_2 for $5/2^+$ state by considering the $5/2^+ \rightarrow 3/2^+$ ($M1$) transition. We have then considered the $7/2^- \rightarrow 5/2^+$ ($E1$) transition and mixing coefficients of the $7/2^-$ level (a_1,b_1) have been estimated using the calculated values of a_2 and b_2. The calculations have been carried out for both ^{35}Cl and ^{35}Ar mirror pair. The result shows that in ^{35}Cl, both $7/2^-$ and $5/2^+$ states are dominated by T=1/2 and have ~4-7% contribution from T=3/2 states. However, in ^{35}Ar, we have found that the $7/2^-$ state has a similar structure of wave function as in ^{35}Cl but the wave function structure of $5/2^+$ level is totally different from ^{35}Cl. It is dominated by T=3/2 (~97%). The results are shown in Table-1.

Table-1: Mixing probabilities in A=35 mirror pair

J^π	^{35}Ar		^{35}Cl	
	a_i^2 in %	b_i^2 in %	a_i^2 in %	b_i^2 in %
$7/2^-$	99.4	0.6	92.7	7.3
$5/2^+$	3.2	96.8	96.1	3.9
$3/2^+$	100	0.0	100	0.0

We have also estimated the transition strengths (B(M1), B(E1) and B(M2)) in ^{35}Cl using our calculated mixings (b^2) and compared them with the experimental values. The results show a great improvement over the pure T=1/2 consideration. In ^{35}Ar, we have estimated the transition strengths but could not compare them with experimental results due to lack of experimental data.

The structural differences between these analog states in A=35 mirror pair thus give the different decay patterns from $7/2^-$ and $5/2^+$ levels.

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