Iso-spin Symmetry breaking in mirror nuclei ^{19}F - ^{19}Ne

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Introduction

The near equality of the masses of proton and neutron corresponds to isospin symmetry in mirror pairs. The Coulomb interaction is the main reason for this symmetry breaking and we can directly investigate the effects of this symmetry breaking by comparing the MED (Mirror Energy Difference) between the analogue states of isospin doublet or TED (Triplet Energy Difference) in isospin triplets. The MED is defined as [1]

$$MED_J = E_J(T, T_z = T) - E_J(T, T_z = +T)$$

As we know the nuclear interaction has some isospin symmetry-breaking components(V_B), we can write the MED as the sum of Coulomb and Isospin Non Conserving (INC) terms of non coulomb origin [1, 2]

$$MED = \triangle_M V_{CM} + \triangle_m V_{Cm} + \triangle_M V_B$$

Here, V_{CM} and V_{Cm} are the multipole and monopole part of the coulomb interactions, respectively, and V_B is an INC term. As Protons revolve around the charged core with a repulsive coulomb potential single particle energy (SPE) of them changes and the exact expression for the change is given by [1]

$$E_{ll} = \frac{-4.5 {Z_{cs}}^{13/12} [2l(l+1) - p(p+3)]}{A^{1/3}(p+3/2)} keV \quad (1)$$

Another SPE correction term is the Electromagnetic Spin-Orbit interaction(E_{ls}) which acts for both proton and neutron (unlike the E_{ll} where it acts only for protons) as they both possess magnetic moments.The simplified expression is given by [1]

$$E_{ls} \approx (g_s - g_l) \frac{1}{2m_N^2 c^2} \left(\frac{-Ze^2}{R_c^3} \right) < \vec{l}.\vec{s} > keV$$

Both the correction of SPE gives actually the monopole coulomb contribution(V_{cm}) of MED.

Results and Discussions

In this present work, we have reproduced the experimental MEDs [3] using shell model calculation. The energy levels of ^{19}F and ^{19}Ne have been calculated using $NUSHELLX$ code [4] up to the $J = \frac{13}{2}^+$ state of the positive parity yrast structure using the sd model space ($1d_{5/2} - 2s_{1/2} - 1d_{3/2}$) and the universal sd interaction. The USD interaction fails to reproduce the MED's.The V_{CM} contribution is added to the calculation by adding a proper coulomb matrix element calculated in the harmonic oscillator (HO) basis. The staggering pattern is observed without a good fit to the experimental MED. The SPE correction for $\pi 1d_{5/2}$ and $\pi 2s_{1/2}$ is -9.17-keV and 64.18-keV that are calculated using eq.(1) which gives V_{ll} monopole coulomb contribution. Adding this contribution to the multipole term could not reproduce the MED Except for the $\frac{3}{2}^+$state. The SPE correction for the spin-orbit interaction is given in Table I.

We can see that the effect of spin-orbit coupling is approximately equal and opposite to the proton and neutron orbitals so when a state is produced by excitation of a proton and neutron simultaneously in a nuclei the contribution to the MED cancels out. But if the production of a state constitutes only one type of nucleon excitation then it largely affects the MED. Both the contribution of V_{ll} and V_{ls} are

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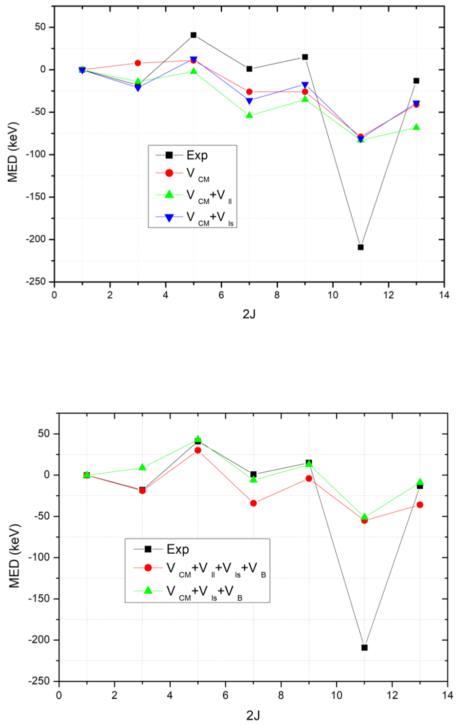

FIG. 1: Experimental and Theoretical MED and ISB contribution to MED.

shown in Fig. 1 together with the contribution V_{CM}.

We can see that the $l-s$ contribution is reproducing better than the $l-l$ contribution. But Overall the the MED can not be reproduced by Considering only the coulomb interaction, we have to add some isospin-breaking potential in our calculation. So the V_B contribution is calculated following the prescription in [2]. We know that The strong interaction has some isovector components which can be calculated by subtracting the coulomb multipole term(Calculated in the HO basis) from the Experimental MED of a known isospin pair. In our case we have taken the ^{23}Na and ^{23}Mg pair [3] and subtracted the V_{CM} contribution from MED of each spin state.

From Table II, we can see that the leading contribution for V_B is coming from $J = \frac{9}{2}^+$ state. So rounding off to 30 keV we assume this Isovector contribution is acting on the

TABLE I: SPE (in keV) for EMSO interaction

Nuclei	$P1d_{5/2}$	$P1d_{3/2}$	$N1d_{5/2}$	$N1d_{3/2}$
^{19}F	-39.79	59.68	33.16	-49.74
^{19}Ne	-44.21	66.32	36.84	-55.26

TABLE II: Coulomb(V_{CM}) and Isovectror(V_B) Energy(in keV)

J^π	$\frac{1}{2}^+$	$\frac{3}{2}^+$	$\frac{5}{2}^+$	$\frac{7}{2}^+$	$\frac{9}{2}^+$	$\frac{11}{2}^+$	$\frac{13}{2}^+$
V_{CM}	0	8	11	-26	-26	-79	-41
V_B	0	-8	-1	1	35.7	-2.4	-1

whole model space. Adding this contribution to the MED reproduced the Experimental MED. But the $\frac{11}{2}^+$ state can't be reproduced.

In conclusion, we can say that the ISB interaction of 30 keV is actually a dominant term that largely affected the MED. Also Neglecting the V_{ll} term from MED in our calculation gives a better fit shown in Figure 1. The $\frac{11}{2}^+$ state can be thought of as a configuration mixing of higher major shells and as we did not take into account the upper shells in our shell model calculation it failed to reproduce the MED for that state.

References

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