Isospin symmetry breaking at high excitation via isovector giant dipole resonance decay in ^{32}S

Debasish Mondal[1*], Deepak Pandit[1], Balaram Dey[1], S. Mukhopadhyay[1], Surajit Pal[1], A. De[2], Srijit Bhattacharya[3] and S. R. Banerjee[1]

[1]*Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata – 700064, INDIA*

[2]*Department of Physics, Raniganj Girls' College, Raniganj – 713347, WB, INDIA*

[3]*Department of Physics, Barasat Govt. College, Barasat, N–24 Pgs, Kolkata – 700124, INDIA*

[*]*email : debasishm@vecc.gov.in*

The concept of charge symmetry and charge independence of the nuclear force is formalized via the concept of isospin quantum number [1]. The isospin symmetry is largely preserved by the nuclear interactions and the main violation occurs owing to the isovector Coulomb interaction which causes mixing of different isospin states. The knowledge of this mixing is important in connection with the width of isobaric analog states [2] and the Fermi β-decay of N ~ Z nuclei around the proton drip line. In general, the breaking of isospin symmetry can be studied experimentally by observing the decays which would have been forbidden by the selection rules if isospin mixing did not take place. Interestingly, the decay of the isovector giant dipole resonance (IVGDR) built on the excited states of self-conjugate nuclei may be used as a probe to study the isospin mixing [3]. The E1 emission, associated with the decay of IVGDR, is hindered in the self-conjugate nuclei populated through T = 0 entrance channel. This is because of the fact that E1 decays from T = 0 to T = 0 states are isospin forbidden; the transitions from T = 0 to T = 1 states are allowed, but there are not many T = 1 final states available to be populated by IVGDR decays. However, the high energy γ–ray yield from self-conjugate nuclei gets enhanced in presence of isospin mixing.The degree of isospin mixing in N ~ Z nuclei has been determined utilizing the GDR γ-decays in few experiments [4-7], but there is no systematic study of isospin mixing with excitation energy (E^*) and still remains an open subject to study.

At the Variable Energy Cyclotron Centre (VECC), Kolkata, we have a plan to study systematically the dependence of isospin mixing on excitation energy in the range 20 – 60 MeV for self-conjugate nucleus ^{32}S for which only a single measurement exists at 58 MeV [5]. In this paper, we report on the isospin mixing at $E^* \sim 30$ MeV for ^{32}S.

The experiment was performed for two systems ^{32}S and ^{31}P populated at nearly same excitation energies but with different entrance channel isospins. ^{31}P was populated only to deduce the statistical model parameters required for the analysis of ^{32}S. The compound nuclei ^{32}S and ^{31}P were formed in T = 0 and T = 1/2 entrance channels by bombarding ^{28}Si (1.0 mg/cm^2) and ^{27}Al (1.0 mg/cm^2) respectively with 35 MeV ^{4}He beam from K-130 cyclotron. The initial excitation energies of ^{32}S and ^{31}P were 37.6 MeV and 40.2 MeV respectively. The high-energy photons from GDR decay were measured using the LAMBDA [8] spectrometer along with a 50-element gamma multiplicity [9] filter to estimate the angular momentum populated in the

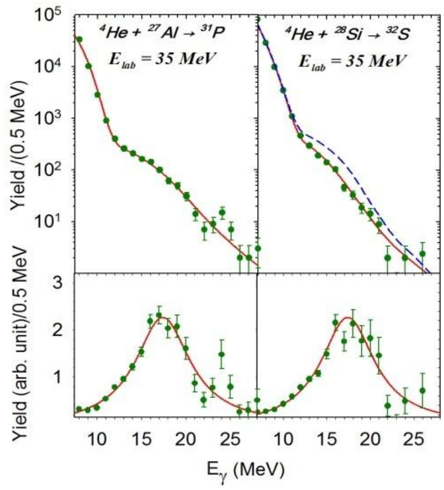

Fig 1: Experimental high energy gamma spectra (green dotted) for ^{31}P (top-left) and ^{32}S (top-right) along with the corresponding CASCADE fits (red solid line). Lower panels show the corresponding linearized GDR plots. Blue short-dashed line (top-right) is the CASCADE calculation for ^{32}S with full mixing.

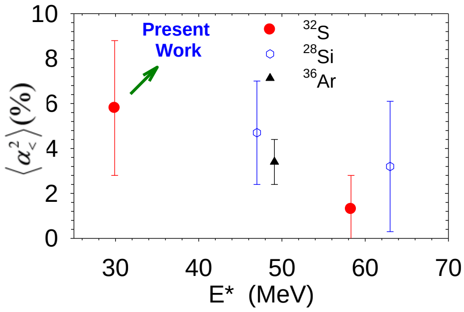

Fig 2: Variation of $\langle\alpha^2_<\rangle$ with excitation energy. In the present work, average rotational energy (7.7 MeV) has been subtracted from the initial excitation energy of the compound nucleus.

compound nucleus as well as to get the start trigger for time of flight (TOF) measurement. The pulse shape discrimination (PSD) technique was applied to reject the pile up events while TOF was used to separate the neutrons from the high-energy gamma rays.

The statistical model calculation was done by using a modified version of CASCADE in which isospin quantum number was taken into account. Two classes of pure isospin states '<' (T = T_z = 0 for self-conjugate nuclei) and '>' (T = T_z+1) were considered. The fraction $[\alpha^2_<]$ of '<' states that mixes with '>' was related to the Coulomb spreading width by [4,10]

$$\alpha^2_< = \frac{\Gamma^\downarrow_< / \Gamma^\uparrow_<}{1+\Gamma^\downarrow_< / \Gamma^\uparrow_< + \Gamma^\downarrow_> / \Gamma^\uparrow_>} \quad (1)$$

where $\Gamma^\downarrow$ is the Coulomb spreading width and $\Gamma^\uparrow$ is the compound nucleus decay width. Similar result holds for '>' states with '<' and '>', signs interchanged. Here $\alpha^2_<$ is angular momentum dependent and one usually reports an average value $\langle\alpha^2_<\rangle$ properly normalized with initial compound nuclear population and gamma yield. The detail of the analysis is discussed in Ref. [4].

In our case, first the statistical model parameters were extracted by fitting the high energy gamma spectrum of ^{31}P with full mixing approximation. These parameters were kept fixed for ^{32}S and the high energy spectrum was fitted by using $\Gamma^\downarrow$ as a free parameter. χ^2 minimization was done in the energy range 10-20 MeV and the best fit value was found to be 13 ± 8 keV corresponding to $\langle\alpha^2_<\rangle = 5.8 \pm 3.0\,\%$, averaged over the angular momentum range 1–32$\hbar$. The high energy spectra for ^{31}P and ^{32}S along with the CASCADE fits are shown in Fig.1.

It is evident from the top-right panel of Fig. 1 that ^{32}S populated through the T = 0 entrance channel shows a suppression in the high energy γ-spectrum compared to that of ^{27}Al populated through T = 1/2 channel. However, the data is not fully suppressed as expected from isospin conservation and gives 5.8% mixing of T = 1 states into T = 0 states. Interestingly, this value of $\langle\alpha^2_<\rangle$, along with the other values obtained for nearby nuclei ^{28}Si [4] and ^{36}Ar [6], clearly shows (Fig. 2) an increasing behavior with the decrease in excitation energy in accordance with Wilkinson's prescription [11]. It says that the mixing is small at low excitation energies owing to the large separation of the states taking part in mixing; gradually increases with increase in energy and attains a maximum value when the separation becomes comparable with Coulomb spreading width; then again decreases due to small compound nuclear life time. However, more data are required at still lower excitation energies and it will be really interesting and also challenging to carry out a systematic investigation on Wilkinson's prediction.

Acknowledgement

The authors would like to thank A. Corsi for providing the isospin included CASCADE code originally obtained from M. Kicinska-Habior.

References

[1] W. Heisenberg, Z. Phys. **78** (1932) 156.
[2] H. Sagawa et al., PLB **444** (1998) 1.
[3] M. N. Harakeh et al., PLB **176** (1986) 297.
[4] J. A. Behr et al., PRL **70** (1993) 3201.
[5] M. Kicinska-Habior et al., NP A **731** (2004) 138.
[6] E. Wojcik et al., Acta Physica Polonica B **37** (2006) 207.
[7] A. Corsi et al., PRC **84** (2011) 041304(R) and references therein.
[8] S. Mukhopadhyay et al., NIM A**582** (2007) 603.
[9] Deepak Pandit et al., NIM A**624** (2010) 148.
[10] H. L. Harney et al., Rev. Mod. Phys **58** (1986) 607.
[11] D. H. Wilkinson, Philos. Mag. **1** (1956) 379.