Isospin Identification for Analogous States in Mirror Nuclei Based on Isospin Symmetry

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Identification of isospin of excited states is not easy. The method to identify isospin for a pair of analogous excited-states in $T = 1/2$, odd-A mirror nuclei is discussed based on the different sensitivity of the $M1$ and Gamow-Teller (GT) transitions for isospin transfers $\Delta T = 0$ and 1.

If charge symmetry of the nuclear interaction is assumed, then isospin is a good quantum number. Every good quantum number is associated with a good symmetry structure. In a $T = 1/2$ mirror-nuclei pair, for every state an analog state of similar structure should be found in the conjugate nucleus (see Fig. 1). Because of the analogous nature of these states, $M1$ and GT transitions from one state or its analog to another state or its analog are all analogous. The analogous transitions are expected to have similar energies and corresponding transition strengths. Therefore, the mirror- and thus the isospin-symmetry properties of the $T = 1/2$ mirror nuclei can be investigated by combining the strength and the energy information of analog transitions in β decay, γ decay, and charge-exchange (CE) and inelastic (IE) reactions (see Ref. [1] for details),

The low-lying states of the mirror nuclei have the isospin $T = 1/2$ because of the $|T_z| = 1/2$ nature of the nuclei. As shown in Fig. 1, above certain excitation energy (about $E_x = 10$ MeV), members of the $T = 3/2$ multiplet states are also allowed. Our interest is to establish the mirror symmetry structure in the high excitation region and to identify the isospin values of excited states based on the isospin symmetry. We notice that the identification of isospin is possible from the different "sensitivity" of inelasitc and charge-exchange type transitions in a pair of $T = 1/2$ mirror nuclei.

From intermediate-energy charge-exchange reactions at 0°, reduced transition strength $B_{CE}(\mathrm{GT})$ for a GT transition is obtained. Using the squared GT (spin-isospin) matrix element, it is given

$$B_{CE}(\mathrm{GT}) = \frac{1}{2J_i + 1} \cdot \frac{1}{2}\, C_{\mathrm{GT}}^2\, \left[M(\sigma\tau)\right]^2, \tag{1}$$

where C_{GT} is the isospin Clebsch-Gordan (CG) coefficient $(T_i T_{zi} 1 \pm 1 | T_f T_{zf})$.

In intermediate-energy hadron inelastic scattering experiments such as (p, p'), the analogous states of the GT states, called $M1$ states, become prominent at forward angles including 0°. They are also excited mainly through $\sigma\tau$ part of the effective nuclear interaction [2, 3].

Because of the analog relationship, the $B_{IE}(\mathrm{GT})$ for inelastic-scattering is givern by

$$B_{IE}(\mathrm{GT}) = \frac{1}{2J_i + 1} \cdot \frac{1}{2}\, C_{M1}^2\, \left[M(\sigma\tau)\right]^2. \tag{2}$$

It should be noted that the CG coefficient is now C_{M1} given by $(T_i T_{zi} 10 | T_f T_{zf})$, where $T_{zf} = T_{zi}$ holds for an $M1$ transition.

Let us examine the ratio of squared CG coefficients in Eqs. 1 and 2 for the transitions starting from the g.s. with $T_i = T_z = +1/2$ nucleus. If the transitions are to the mutually analogous $T_f = 1/2$ states with $T_z = \pm(1/2)$, the factor 1/2 is obtained as the ratio of squared CG coefficients for inelasitc and charge-exchange type transitions. On the other hand if the transitions are to the analogous $T_f = 3/2$ states with $T_z = \pm(1/2)$, the factor 2 is obtained as the ratio (see also Fig. 1). The $M1$ transition to a $T_f = 3/2$ state, therefore, is enhanced in total by a factor of 4 than the corresponding GT transition to the analog $T_f = 3/2$ state, if transition strengths are normalized by the corresponding $M1$ and GT transitions to analogous $T_f = 1/2$ states.

In order to study the strengths of the $M1$ transitions, a (p, p') reaction at 0° was performed at IUCF, Indiana using the K600 spectrometer [4]. In order to see whether or not the scheme using the different sensitivity of $M1$ and GT transitions to different T_f states works as a method to identify the isospin of a state, the comparison was made for the spectra of mirror nuclei pair ^{13}C and ^{13}N obtained in inelastic scattering and charge exchange reactions, $^{13}\mathrm{C}(p, p')$ and $^{13}\mathrm{C}(^3\mathrm{He}, t)^{13}\mathrm{N}$, respectively. The (p, p') spectrum was measured using the transmission mode of the K600 spectrometer placed at 0°, where the momentum of a scattered particle is very close to the incident beam momentum. After passing through the spectrometer, the beam was dumped in a Faraday cup placed at the high-radius end of the focal plane of the spectrometer [4]. At the incident energy of 160 MeV, a resolution of 40 keV has been obtained for a 3.9 mg/cm^2 target after performing the dispersion matching for the compensation of momentum spread of the incident beam [5, 6]. The condition of minimum background from the beam halo was always seeked by tuning the beam line and cyclotron conditons. A very clean 0° spectrum was obtained for the excitation-energy region above 8 MeV. The obtained (p, p') spectrum is compared with the $^{13}\mathrm{C}(^3\mathrm{He}, t)^{13}\mathrm{N}$ spectrum in Fig. 2. Due to the different sensitivity, we can clearly see that the $T = 3/2$ state at 15.11 MeV is enhanced.

In ^{27}Al and ^{27}Si system, the level density becomes very high in the mixed T region ($E_x \geq 10$ MeV) although $\Delta L = 0$ and $\Delta S = 0$ states are strongly selected at 0°. From a comparison of $^{27}\mathrm{Al}(^3\mathrm{He}, t)$ spectrum newly measured with a resolution of 90 keV at RCNP (see the contribution by H. Fujita *et al.* in this volume) and $^{27}\mathrm{Al}(p, p')$ spectrum at IUCF, the identification of isospin is in progress for each analogous pair states. There are prominent states at around $E_x = 11.5$ MeV region in the (p, p') spectrum. It is suspected that these states are of $T_>$ ($T = 3/2$) nature judging from the enhanced strengths in the $M1$-type (p, p') reaction.

References

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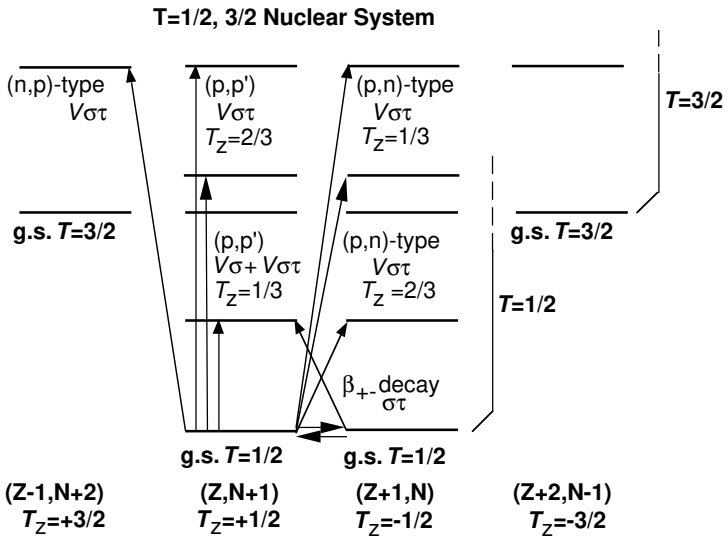

Figure 1: Schematic isospin-symmetry structures for $T_z = \pm 1/2$, odd-A mirror nuclei and the neighboring $T_z = \pm 3/2$ nuclei. The effect of Coulomb displacement energies for different Z nuclei are excluded to show the symmetry structure based on isospin. Analogous transitions connecting the ground states in the mirror nuclei with excited states in the same and the conjugate nuclei are indicated.

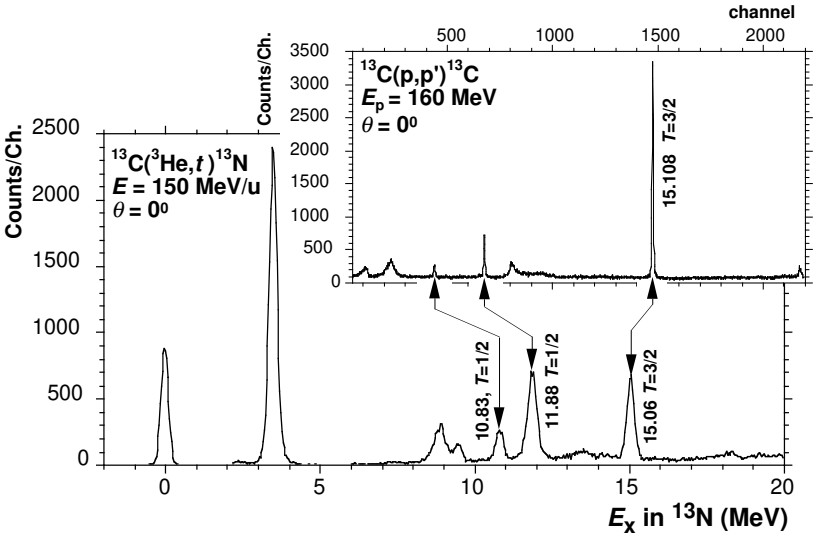

Figure 2: The comparison between the 0° ^{13}C(p,p') and ^{13}C$(^3\mathrm{He},t)^{13}$N spectra at the region of excitation energy where both known $T = 1/2$ and $T = 3/2$ states are mixed. Due to the different sensitivity for the $T_<$ $(T = 1/2)$ and $T_>$ $(T = 3/2)$ states, $T_>$ $(T = 3/2)$ state at 15.11 MeV is enhanced by about a factor of 4 in the (p,p') spectrum.