Isoscalar and Orbital Contributions in $M1$ Transitions Studied through the Symmetry Structure of $A = 27$ Mirror Nuclei

Y. Fujita,[a] H. Akimune,[b] I. Daito,[b] H. Fujimura,[b] M. Fujiwara,[b] M. N. Harakeh,[c] T. Inomata,[a] J. Jänecke,[d] K. Katori,[a] A. Tamii,[e] M. Tanaka,[f] H. Ueno,[a] and M. Yosoi[e]

[a]*Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[b]*Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan*
[c]*Kernfysisch Versneller Instituut, Zernikelaan 25, 9747 AA Groningen, The Netherlands*
[c]*Department of Physics, University of Michigan, Ann Arbor, Michigan 48109, USA*
[e]*Department of Physics, Kyoto University, Sakyo, Kyoto 606-8224, Japan*
[f]*Kobe Tokiwa Jr. College, Nagata, Kobe 653-0824, Japan*

In a 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, $M1$ and GT transitions from some 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, which are caused by the weak, electromagnetic (EM), and strong interactions, respectively.

The $M1$ transitions are caused by the magnetic dipole ($M1$) interaction whose operator consists of an orbital part $g_\ell \boldsymbol{\ell}$ and a spin part $g_s \boldsymbol{s}$ $[= (1/2) g_s \boldsymbol{\sigma}]$. The $M1$ operator is further rewritten as the sum of IS and IV components.

On the other hand, GT β decays is caused by a simple $\sigma\tau$-type operator. The situation is almost similar in hadron CE reactions at intermediate energies at 0° (in the limit of $q = 0$), because spin-isospin type interaction is dominant under such conditions [1, 2].

Assuming the dominance of the $\sigma\tau$-type operator, which is mostly true for EM interaction as well as for strong interaction using hadronic probes at intermediate energy at 0°, there is a "quasi" proportional relationship between the transition strengths $B(M1)$ and $B(\mathrm{GT})$, as explained in detail in Ref. [3]

$$B(M1) \approx \frac{3}{8\pi} \, (\mu_\mathrm{p} - \mu_\mathrm{n})^2 \, \frac{C^2_{M1}}{C^2_\mathrm{GT}} \, B(\mathrm{GT}). \tag{1}$$

For the direct comparison between the values $B(\mathrm{GT})$ and $B(M1)$, we define a renormalized value $B^R(M1)$ as a value $B(M1)$ divided by the factor in front of $B(\mathrm{GT})$.

We studied $M1$ and GT transitions in the mirror-nuclei pair ^{27}Al and ^{27}Si connected with the g.s. of one of the two nuclei. $B(M1)$ values for the $M1$ transitions in ^{27}Al are deduced from the data on γ decay up to $E_x = 8.5$ MeV, where the proton decay starts [4]. The good-resolution (p, n)-type CE reaction, (^{3}He,t) reaction, at 150 MeV/u performed at RCNP with a resolution of 160 keV is used to study $B(\mathrm{GT})$ values up to high excitation region based on the proportionality between the cross sections at 0° and the $B(\mathrm{GT})$ values. The symmetry structure in the mirror nuclei ^{27}Al and ^{27}Si is studied not only from the correspondence of excitation energies, but also from the "quasi" proportionality of $B(M1)$ and $B(\mathrm{GT})$ values for the analogous transitions from the g.s. of ^{27}Al. As a result of careful comparison of both excitation energies and transition strengths, the mirror-symmetry properties of the mirror-nuclei pair ^{27}Al and ^{27}Si have been established up to $E_x = 8.5$ MeV (see Ref. [3] for details).

Although we have seen a good overall correspondence for the states in ^{27}Al and in ^{27}Si, there are noticeable differences in the strengths $B^R(M1)$ and the $B(\mathrm{GT})$ of the corresponding states in a level-by-level comparison. The differences can be attributed to the different nature of the operators involved in the γ-decay and the $(^3\mathrm{He}, t)$ reaction. In an $M1$ transition between states with $T = 1/2$, not only the dominant IV spin term but also the minor IS term can make some contributions. Furthermore, the orbital contribution, although usually believed to be small, can sometimes be significant [5]. Since the interferences of the IS term and/or the IV orbital term and the IV spin term are either constructive or destructive depending on the structure of the state, it is expected that the differences in strengths by up to ~ 50 % might be expected compared to a pure GT transition [6, 7].

By comparing the analogous $B(M1)$ and $B(\mathrm{GT})$ strengths, it is possible to extract the combined contribution of the IS term and the IV orbital term in the $B(M1)$ strength. The ratio of $B^R(M1)$ and $B(\mathrm{GT})$ for the jth pair of corresponding states

$$R^j_{\mathrm{ISO}}(M1/\mathrm{GT}) = \frac{B^R_j(M1)}{B_j(\mathrm{GT})} \cdot \frac{1}{R_{\mathrm{MEC}}}, \tag{2}$$

should show the combined IS-orbital contribution to the jth $M1$ transition and indicate how the IV spin term is modified. Where R_{MEC} is the enhancement factor of $M1$ transition strengths from meson-exchange currents, and the value 1.4 was used [3].

The R_{ISO} should be greater than unity if the combined contributions are constructive and less for the destructive case. The results are shown in Fig. 2 for the $M1$ transitions in ^{27}Al as a function of $B(M1)\uparrow$ value. It is interesting to note that the R_{ISO} value tends to deviate from unity by more than a factor of two when the $B(M1)\uparrow$ is less than approximately 0.1. This shows that the combined IS-orbital contribution is rather large in weaker transitions and the "quasi" proportionality of the $B(M1)$ values for $\Delta T = 0$ $M1$ transitions and the analogous $B(\mathrm{GT})$ values is lost. This finding is interpreted as follows; since the IS term and the IV orbital term are always small, the dominance of the IV spin term of the $M1$ operator is guaranteed if the transitions are at least of average strength. The IV spin term, however, can also be small. Then the relative contribution of the IS term and the IV orbital term becomes significant although the transition itself is weak.

References

[1] W. G. Love and M. A. Franey, Phys. Rev. C **24** (1981) 1073.
[2] T. N. Taddeucci *et al.*, Nucl. Phys. **A469** (1987) 125.
[3] Y. Fujita *et al.*, Phys. Rev. C **59** (1999) 90.
[4] P. M. Endt, Nucl. Phys. **A521** (1990) 1, and references therein.
[5] Y. Fujita *et al.*, Phys. Rev. C **55** (1997) 1137.
[6] E. K. Warburton and J. Weneser, *Isospin in Nuclear Physics*, ed. D. H. Wilkinson, (North-Holland, Amsterdam, 1969) Chap. 5.
[7] S. S. Hanna, *Isospin in Nuclear Physics*, ed. D. H. Wilkinson, (North-Holland, Amsterdam, 1969) Chap. 12.

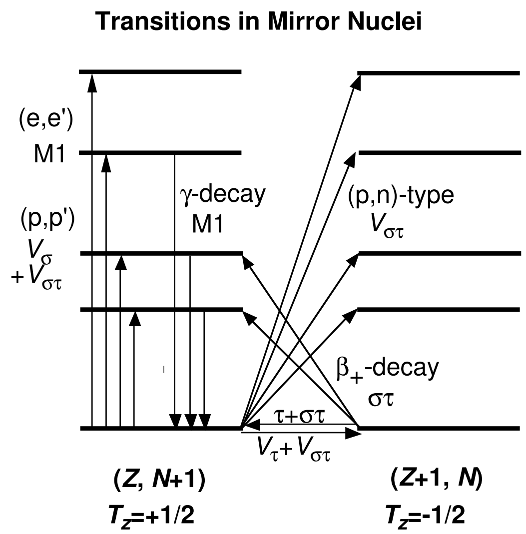

Figure 1: Schematic isospin-symmetry structures for $T_z = \pm 1/2$, odd-A mirror nuclei. Analogous transitions connecting the ground states in the mirror nuclei with excited states in the same and the conjugate nuclei are indicated.

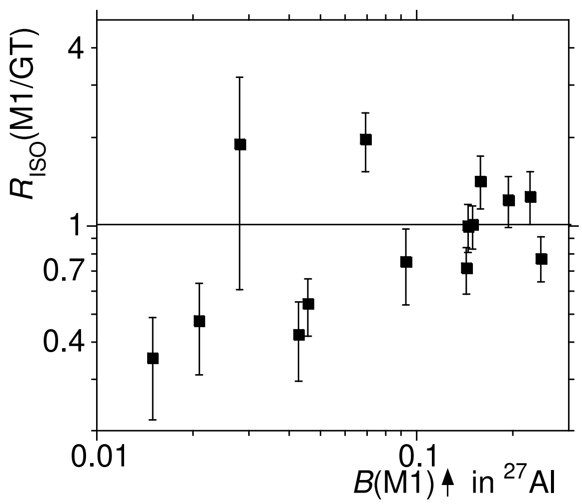

Figure 2: The ratio R_{ISO} for the $M1$ transitions in ^{27}Al as a function of $B(M1)\uparrow$ ($B(M1)$ from the ground state to an excited state). The ratio is sensitive to the combined contribution of IS term and IV orbital term in each $M1$ transition. Values of $R_{\mathrm{ISO}} > 1 (< 1)$ suggest constructive (destructive) interference of these terms with the IV spin term. For the definition of R_{ISO}, see text.