Isospin symmetry of $T_z = \pm 3/2 \rightarrow \pm 1/2$ Gamow-Teller transitions in $A = 41$ nuclei

Y. Fujita[1] Y. Shimbara[1] T. Adachi[1] G.P.A. Berg[2,3] B.A. Brown[4] H. Fujita[1] K. Hatanaka[2] J. Kamiya[2] K. Nakanishi[2] Y. Sakemi[2] S. Sasaki[5] Y. Shimizu[2] Y. Tameshige[2] M. Uchida[6] T. Wakasa[2] and M. Yosoi[6]

[1] *Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*

[2] *Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan*

[3] *Kernfysisch Versneller Instituut, Zernikelaan 25, 9747 AA Groningen, The Netherlands*

[4] *NSCL and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824*

[5] *Shizuoka Institute of Technology, Fukuroi, Shizuoka 437-8555, Japan*

[6] *Department of Physics, Kyoto University, Sakyo, Kyoto 606-8502, Japan*

Isospin is a good quantum number under the assumption that the nuclear interaction is charge symmetric. As such, an analogous structure is expected for the same mass A nuclei with different T_z (isobars), where T_z [$=(N-Z)/2$] is the z component of the isospin T (see, e.g., Refs. [1, 2]). Gamow-Teller (GT) transitions, caused purely by the $\sigma\tau$-type operator, are well suited for the study of analog states and properties of analogous transitions, because they can be studied in both β decay and hadron charge-exchange (CE) reactions.

The simplest analogous GT transitions are expected for the odd-mass mirror nuclei with $T_z = \pm 1/2$. By comparing the GT transitions from the ground states of $T_z = -1/2$ and $+1/2$ nuclei to excited states of $T_z = +1/2$ and $-1/2$ nuclei studied in β decays and (p,n)-type CE reactions, respectively, the symmetry of analogous transitions and analog states, and thus the isospin symmetry of isobars, has been discussed in the low-lying region of various sd-shell nuclei [3, 4, 6, 5]. Similarly, the symmetric nature of $T_z = \pm 1$ to $T_z = 0$ GT transitions has been examined for a few systems of light sd-shell nuclei, such as the $A = 26$ nuclei system (^{26}Mg, ^{26}Al and ^{26}Si) [7, 8] or the $A = 38$ system (^{38}Ar, ^{38}K and ^{38}Ca) [9] by comparing (p,n) or $(^3\mathrm{He},t)$ CE reactions and β-decay studies.

The symmetry of systems with larger isospin T is challenging. The $T_z = -T$ nuclei, unlike stable $T_z = T$ nuclei, are usually far away from the β-stability line, and it is expected that the "isospin asymmetric features", if any, are observed better. The isospin structure and analogous transitions of the so-called "$T = 3/2$ system", after subtracting the Coulomb displacement energy, are schematically shown in Fig. 1. The isobaric analog states of the $T = 3/2$ ground states of the $T_z = \pm 3/2$ nuclei are called the IAS in the $T_z = \pm 1/2$ nuclei.

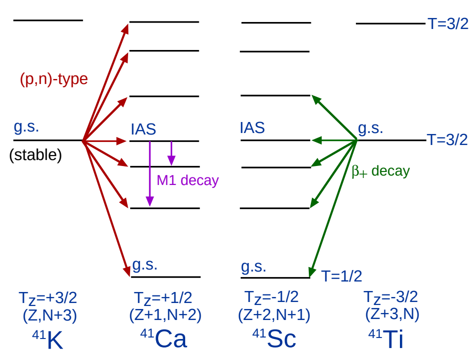

Figure 1: Schematic view of the isospin analog states and analogous transitions in the $A = 41$, $T_z = \pm 3/2$ and $\pm 1/2$ isobar system. The Coulomb displacement energies are removed so that the isospin symmetry of the states and transitions become clearer. The type of the reaction or decay is shown along the arrow indicating the transition.

Among the candidates for the $T_z = \pm 3/2 \rightarrow \pm 1/2$ comparison, we find that analogous transitions in the $A = 41$ system, i.e., ^{41}K ($T_z = +3/2$) to ^{41}Ca ($T_z = +1/2$) and ^{41}Ti ($T_z = -3/2$) to ^{41}Sc ($T_z = -1/2$), are well suited for an accurate study of the analogous GT transitions and also the isospin symmetry structure of isobars. The former can be studied by a CE reaction on a stable ^{41}K target, and the latter in the β decay of ^{41}Ti. Owing to the high Q_{EC} value of 12.93 MeV in the ^{41}Ti β decay, the $B(\mathrm{GT})$ values have been reported for ^{41}Sc up to about 8 MeV [10, 11].

The $^{41}\mathrm{K}(^3\mathrm{He},t)^{41}\mathrm{Ca}$ experiment was performed at the high energy-resolution facility of RCNP, consisting of the "WS course" and the Grand Raiden spectrometer using a 140 MeV/nucleon ^{3}He beam from the $K = 400$ Ring Cyclotron [12]. An energy resolution of 35 keV (FWHM) was achieved. In order to produce a thin ^{41}K self-supporting target, a thin foil of $^{41}\mathrm{K_2CO_3}$ supported by polyvinylalcohol (PVA) [13] was used.

In order to identify $L = 0$ GT states, yields were derived for all states in the spectra with angle cuts $\Theta = 0° - 0.5°$ (see Fig. 2), $0.5° - 1.0°$, and $1.0° - 1.5°$, and angular distributions having peak at 0° were studied. It was found that most of the well observed states below $E_x = 6$ MeV showed $L = 0$ nature. In order to obtain $B(\mathrm{GT})$ values, we have to determine the unit cross section $\hat{\sigma}_{\mathrm{GT}}$, or the "unit GT intensity" for the transitions to the states observed in the $^{41}\mathrm{K}(^3\mathrm{He},t)^{41}\mathrm{Ca}$ spectrum at 0°. We assume that the total sum of $B(\mathrm{GT})$ values in the analogous mirror transitions, i.e., $T_z = \pm 3/2 \rightarrow \pm 1/2$ GT transitions, observed in the $^{41}\mathrm{K}(^3\mathrm{He},t)$ reaction and in the ^{41}Ti β decay are the same (see Fig. 1). From Fig. 2, we see that most of the prominent levels are

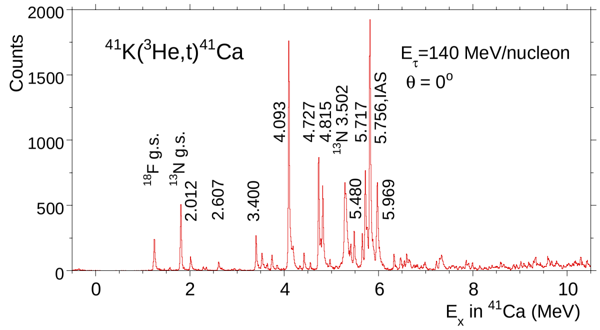

Figure 2: The ^{41}K(^{3}He, t)^{41}Ca spectrum at 0° with an angular range up to 0.5°. A high resolution of 35 keV has been achieved. The major GT states are indicated by their excitation energies. For other details, see text.

concentrated in the $E_x = 4-6$ MeV region. As discussed, most of them have $L = 0$. A similar concentration of GT strength was reported in the corresponding $E_x = 4-6.2$ MeV region of ^{41}Sc [10, 11]. The unit GT intensity was obtained by assuming that the total intensity summed over all GT states in this region, after making a correction for excitation energy, corresponds to the B(GT) value of 1.68(12), which is the average of the ΣB(GT) values of the two β-decay studies. The main part of the GT strength is concentrated at $E_x = 4-6$ MeV and it is very fragmented. Clustering of states is observed around 4.1, 4.75, 5.7, and 5.95 MeV.

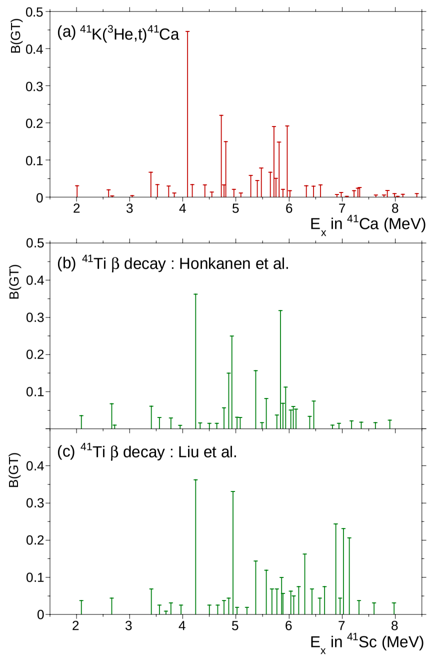

Figure 3: Experimental B(GT) distributions from $T_z = \pm 3/2 \rightarrow \pm 1/2$ isospin mirror transitions. (a) B(GT) distribution from the present ^{41}K(^{3}He, t)^{41}Ca reaction. (b) B(GT) distribution from the ^{41}Ti $\rightarrow^{41}$Sc β decay reported in Ref. [10]. (c) B(GT) distribution from the ^{41}Ti $\rightarrow^{41}$Sc β decay reported in Ref. [11]. Owing to the high $Q_{\rm EC}$ value of the ^{41}Ti β decay, the B(GT) values was studied for states in ^{41}Sc with relatively high excitation energies. Because of the low S_p value of 1.09 MeV in ^{41}Sc, both distributions were derived from measurements of delayed protons. Similar clustering strengths can be seen at 4.25, 4.9, and 5.8 MeV, although the strengths are distributed somewhat differently in each cluster. On the other hand, at higher excitations above 6.2 MeV, we see that these two β-decay results differ substantially.

The GT strength distribution from our ^{41}K(^{3}He, t) study is shown in Fig. 3(a) for the energy region where the β-decay results are available. It is clear that this distribution is quite similar to the one of Honkanen et al. [10] shown in Fig. 3(b) with respect to the gross structure. Furthermore, since the experimental resolutions in this β-decay measurement (30 keV) and the (^{3}He, t) reaction (35 keV) are both good and similar, we see one-to-one correspondence of observed states and the GT transition strengths to them for the energy region below 6.2 MeV, where the main part of the GT strength is concentrated.

For details see Ref. [14].

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