# High resolution study of Gamow-Teller transitions in $pf$-shell nuclei


T. Adachi[1], Y. Fujita[2], P. von Brentano[3], G.P.A. Berg[4], N.T. Botha[5] C. Fransen[3], D. De Frenne[6], H. Fujita[7], K. Fujita[1], H. Hashimoto[1], K. Hatanaka[1], E. Jacobs[6], J. Kamiya[1], K. Kawase[1], M. Matsubara[1], K. Nakanishi[8], A. Negret[9], R. Neveling[10], T. Ohta[1], N. Pietralla[3], L. Popescu[11], Y. Sakemi[12], Y. Shimbara[13], Y. Shimizu[1], C. Scholl[3], Y. Tameshige[1], A. Tamii[1], M. Uchida[14], T. Wakasa[15], M. Yosoi[1], R.G.T. Zegers[13], and K.O. Zell[3]

[1] *Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan*
[2] *Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[3] *Institut für Kernphysik, Universität zu Köln, 50937 Köln, Germany*
[4] *Department of Physics, University of Norte Dame, Norte Dame, IN, 46556, USA*
[5] *Department of Physics, University of Cape Town, Rondebosch 7701, South Africa*
[6] *Vakgroep Subatomaire en Stralingsfysica, Universiteit Gent, B-9000 Gent, Belgium*
[7] *School of Physics, University of the Witwatersrand, Johanesburg, 2050, South Africa*
[8] *Center for Nuclear Study, University of Tokyo, RIKEN campus, Wako, Saitama, 351-0198, Japan*
[9] *Commiss European Commission, Joint Research Centre, Institute for Reference Materials and Measurements (IRMM), Retieseweg 111, B-2440 Geel, Belgium*
[10] *iThemba LABS, Somerset West 7129, South Africa*
[11] *Kernfysisch Versneller Instituut, Zernikelaan 25, 9747 AA Groningen, The Netherlands*
[12] *Cyclotron and Radioisotope Center (CYRIC), Tohoku University, Miyagi, 980-8578, Japan*
[13] *National Superconducting Cyclotron Facility, Michigan State University, East Lansing, MI 48824, USA*
[14] *Department of Physics, Tokyo Institute of Technology, Oh-okayama, Meguro, Tokyo 152-8550, Japan*
[15] *Department of Physics, Kyushu University, Higashi, Fukuoka 812-8581, Japan*


In the early stage of the core collapse of supernovae, electron capture and $\beta$ decay of $pf$-shell nuclei become important processes [1]. These processes are dominated by Gamow-Teller (GT) (and also by Fermi) transitions.

In order to study GT transition strengths $B(\mathrm{GT})$ in a wide excitation energy, we use $(^3\mathrm{He},t)$ reaction at an incident energy of 140 MeV/nucleon (MeV/u) at RCNP. A proportionality between measured cross sections extrapolated at zero momentum transfer and $B(\mathrm{GT})$ values, "$\sigma_{\mathrm{GT}} = \hat{\sigma}_{\mathrm{GT}} B(\mathrm{GT})$", is shown [2]. The $\hat{\sigma}_{\mathrm{GT}}$ is called a unit cross section for a specific nuclear mass number $A$. Once a "standard $B(\mathrm{GT})$" value for one transition is measured by a $\beta$ decay, the $\hat{\sigma}_{\mathrm{GT}}$ is obtained.

We examined GT transitions from $T_z = +1$ $pf$-shell nuclei ($^{42}$Ca, $^{46}$Ti [3], $^{50}$Cr [4] and $^{54}$Fe) to $T_z = 0$ nuclei ($^{42}$Sc, $^{46}$V, $^{50}$Mn and $^{54}$Co). Energy resolutions were 60, 33, 29 and 21 keV, respectively. The energy spectra are shown in Fig. 1.

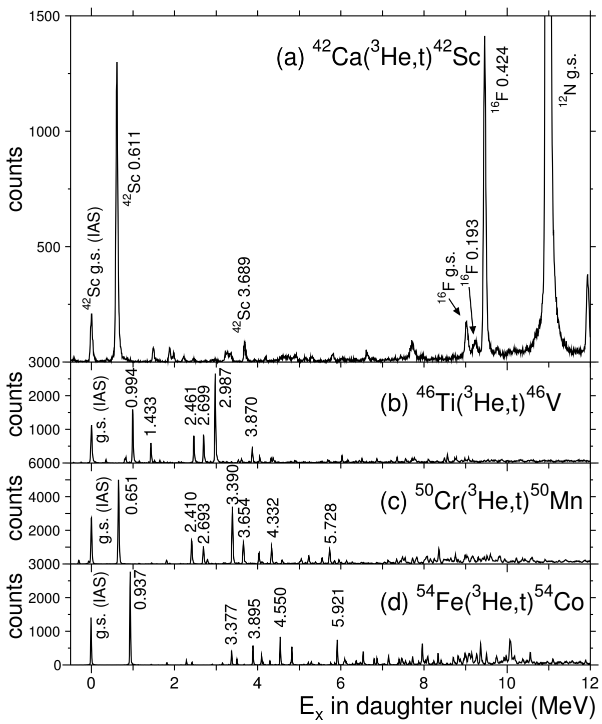


Figure 1: High resolution energy spectra of $(^3\mathrm{He},t)$ reaction on target nuclei (a) $^{42}$Ca, (b) $^{46}$Ti, (c) $^{50}$Cr and (d) $^{54}$Fe for up to 12 MeV and the scattering angle $\theta \leq 0.5$ °.

If the isospin symmetry of nuclear structure is assumed, the $B(\mathrm{GT})$ value of the $T_z = -1 \to 0$ transition is used as the "standard $B(\mathrm{GT})$" value. For these cases, no reliable $\beta$-decay data were available. We use the transition strength to Isobaric Analog State (IAS) as a standard assuming the following: (1) all the Fermi transition strengths concentrate in the IAS, and it consumes the sum-rule strengths of $B(\mathrm{F}) = |N - Z|$, and (2) the ratio of GT and Fermi unit cross-sections denoted by $R^2$ value $(= \hat{\sigma}_{\mathrm{GT}}/\hat{\sigma}_{\mathrm{F}})$ [5] is a constant for a given mass number $A$. The $R^2$ values have been experimentally determined for several $A$ systems in which $B(\mathrm{GT})$ values can be directly be evaluated from $\beta$-decay studies. For heavier nuclei, we could determine the $R^2$ values for the cases in which the g.s. $\leftrightarrow$ g.s. transitions between the target and daughter nuclei are GT transitions. For lighter nuclei, $R^2$ values were determined by assuming the isospin symmetry of the $T_z = \pm 1/2 \to \mp 1/2$ GT transitions for the $T = 1/2$ systems, and $T_z = \pm 1 \to 0$ GT transitions for the $T = 1$ system. The $R^2$ values were obtained for the region of $7 \leq A \leq 178$ systems.

In addition, $R^2$ values were derived for $A = 42$ and 50 systems in the newly proposed "merged analysis" [4] of $(^3\mathrm{He}, t)$ and isospin-symmetry $\beta$-decay data. By combining the half life $T_{1/2}$ of the $\beta$ decay, the $R^2$ values for the $A = 42$ [$^{42}\mathrm{Ca}(^3\mathrm{He}, t)$ reaction] and $A = 50$ [$^{50}\mathrm{Cr}(^3\mathrm{He}, t)$ reaction] were derived.

The smooth increase of $R^2$ values as a function of $A$ was observed. By making the second order fit, $R^2$ values for $A = 46$ and $A = 54$ were derived.

The obtained $B(\mathrm{GT}_-)$ distributions starting from these $pf$-shell nuclei are shown in Fig. 2. Most of the $\mathrm{GT}_-$ strengths concentrate at $E_x = 0.611$ MeV in $^{42}$Sc. The $\mathrm{GT}_-$ strengths move to higher excitation energies as mass number increases.

The cumulative sum of $B(\mathrm{GT}_-)$ values up to 12 MeV are shown in Fig. 3. The sum increases at $E_x = 2-4$ MeV in $^{46}$V, $E_x = 3-5$ MeV in $^{50}$Mn and $E_x = 9-11$ MeV in $^{54}$Co. The sum rule of GT strengths is known as $\Sigma B(\mathrm{GT}_-) - \Sigma B(\mathrm{GT}_+) = 3(N-Z)$, where $\Sigma B(\mathrm{GT}_-)$ and $\Sigma B(\mathrm{GT}_+)$ are the sum of $\mathrm{GT}_-$ and $\mathrm{GT}_+$ transition strength measured by $(p, n)$ and $(n, p)$ types reactions, respectively. Observed $\Sigma B(\mathrm{GT}_-)$ starting from the $T_z = +1$ target nuclei is expected to have more than $3(N-Z) = 6$. The experimental $\Sigma B(\mathrm{GT}_-)$ consume 45 %, 50 %, 55 % and 70 % of 6 for $^{42}$Sc, $^{46}$V, $^{50}$Mn and $^{54}$Co, respectively, in the $E_x$ region up to 12 MeV.

By using high resolution $(^3\mathrm{He}, t)$ reactions, the project to obtain $B(\mathrm{GT}_-)$ distributions in $pf$-shell nuclei is in progress. It is expected that they can be used for the understanding of various astrophysical phenomena.

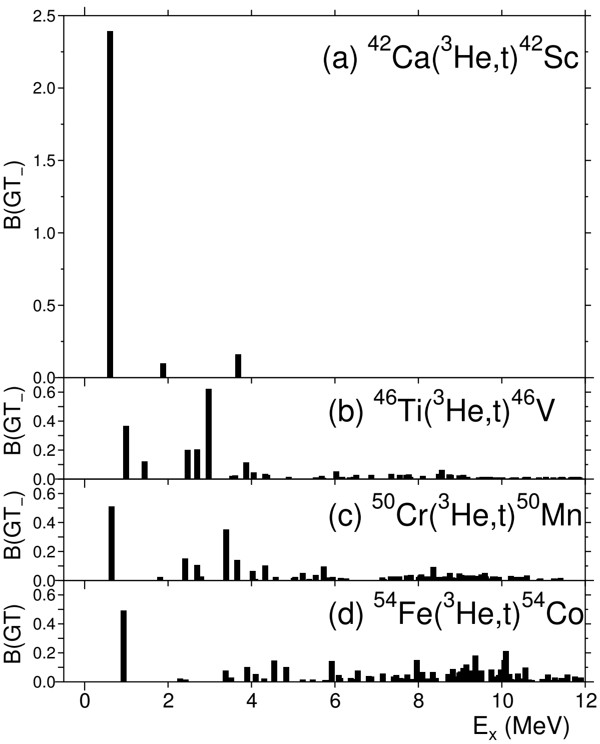


Figure 2: The $B(\mathrm{GT})$ distribution in (a) $^{42}$Sc, (b) $^{46}$V, (c) $^{50}$Mn and (d) $^{54}$Co. Note the change of the ordinate range of the panels.

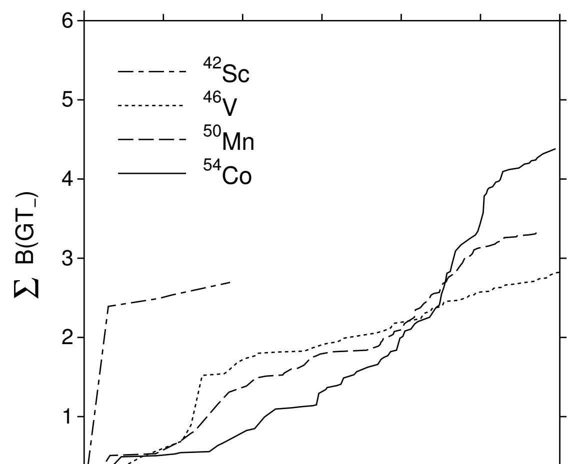


Figure 3: The cumulative sum of $B(\mathrm{GT})$ values up to 12 MeV. Dotdashed line is $^{42}$Sc, doted line is $^{46}$V, dashed line is $^{50}$Mn and solid line is $^{54}$Co.

## References


[1] K. Langanke and G. Matínez-Pinedo, Nucl. Phys. **A673**, 481 (2000).

[2] Y. Fujita et. al., Phys. Rev. C **67**, 064312 (2003).

[3] T. Adachi, et. al., Phys. Rev. C **73**, 024311 (2006).

[4] Y. Fujita et al., Phys. Rev. Lett. **95**, 212501 (2005).

[5] T.N. Taddeucci, et. al., Nucl. Phys. **A469**, 125, (1987).