Observation of T=1 and T=0 Gamow-Teller States in the 54Fe(p,n)54CO Reaction

著者	Orihara H., Murakami T., Nishihara S., Nakagawa T., Maeda K., Miura K., Ohnuma H.
journal or publication title	CYRIC annual report
volume	1980
page range	36-39
year	1980
URL	http://hdl.handle.net/10097/48563

CYRIC
Annual Report 1980

V. 1 Observation of T=1 and T=0 Gamow-Teller States in the ^{54}Fe(p,n)^{54}Co Reaction

Orihara H., Murakami T.*, Nishihara S.*, Nakagawa T.*, Maeda K.**, Miura K.***, and Ohnuma H.****
Cyclotron and Radioisotope Center, Tohoku University
Department of Physics, Faculty of Science, Tohoku University*
College of General Education, Tohoku University**
Tohoku Institute of Technology***
Department of Physics, Tokyo Institute of Technology****

A search for the states carrying a significant fraction of the Gamow-Teller (GT) strength has been the subject of many recent charge exchange reaction studies. The GT strength for the $T_<$ states has been observed in many nuclei, and comparisons of the strength with β-decay and M1 matrix elements have been made. Recently a broad peak around 13.4 MeV was observed in the ^{90}Zr(p,n)^{90}Nb reaction,[1] and has been identified as the state with $T_>$ GT strength. On the other hand in the ^{48}Ca(p,n)^{48}Sc reaction the GT strength has been found[2] concentrated in a peak at E_x = 16.8 MeV in ^{48}Sc, and an upper limit of 280 keV is set for its width. The position and the strength of this peak is in good agreement with the shell-model calculation.[3] This state seems only weakly excited in the ^{48}Ca(^{3}He,t)^{48}Sc reaction.[3] Gaarde et al. studied[4] the (^{3}He,t) reaction on another N = 28 nucleus ^{54}Fe at $E_{^3\mathrm{He}}$ = 70 MeV. They observed many states excited by ℓ = 2 transitions, most of which were identified as 1^+. However the interpretation is somewhat obscured by the complicated reaction processes involved. In the course of a systematic investigation of the (p,n) reactions on nuclei around A = 56, we have observed a prominent peak at E_x = 10.23 MeV in the ^{54}Fe(p,n)^{54}Co reaction at E_p = 32 and 35 MeV. The angular distribution of this peak indicates $J^\pi = 1^+$, and we tentatively assign this state to be the $T_>$ GT state in ^{54}Co. Another peak at E_x = 5.32 MeV is interpreted as the T = 0 component of the GT state.

The experiment was performed using 32- and 35-MeV proton beams from the AVF cyclotron and the time-of-flight facilities at Cyclotron and Radioisotope Center, Tohoku University. We have utilized a beam swinger system, and measured angular distributions of emitted neutrons between 0° and 90°. Details of the time-of-flight facilities will be published elsewhere.[5] The target was prepared by rolling of metallic iron, enriched to 97.6 %, and the thickness was 6.1 mg/cm^2.

A representative neutron energy spectrum, corrected for the detector efficiency, is shown in Fig. 1. Overall time resolution was 1.3 nsec, which corresponded to the energy spread of 95 keV (FWHM) in the vicinity of E_x = 10.23 MeV. In addition to the ground state, which is the isobaric analog state (IAS) of the ground state of ^{54}Fe, and the known states at 0.94 MeV(1^+, T=0) and 1.45 MeV(2^+, T=1), several states are seen to be excited at higher energies. Especially interesting is a prominent peak at 10.23 MeV, since a state with strong $T_>$ GT strength has been predicted in this energy region.[4] The distribution of 1^+ strengths by the shell-model calculation of Gaarde et al.[4] is shown in the upper part of Fig. 1. We estimated the width of the 10.23-MeV state to be (95 ± 30) keV by quadratically substracting the contributions of time spread and the target thickness from the observed peak width. Another peak at E_x = 5.32 MeV is also conspicuous. The intensities of these peaks decrease rapidly with decreasing incident energy. Figure 2 shows the angular distributions for the ground state, 0.94-MeV, 5.32-MeV and 10.23 MeV states at E_p = 35 MeV.

Solid curves in Fig. 2 show distorted-wave Born approximation (DWBA) predictions calculated by the code DWBA-70, which includes knock-on exchange contributions.[6] The effective interaction for the reaction has been taken to be the phenomenological nucleon-nucleon force[7] with a 1.0-fm Yukawa radial dependence and V_0 = 27 MeV, $V_\sigma = V_{\sigma\tau}$ = 12 MeV and V_τ = 18 MeV. This interaction has been successfully used[8] in the analysis of many (p,n) analog transitions between E_p = 25 and 45 MeV. Optical-potential parameters of Becchetti and Greenlees[9] are used for protons. Those for neutrons are self-consistent neutron optical potential parameters derived by Carlson et al.[10] from the Becchetti-Greenlees potentials. Pure ($\pi f_{7/2}^{6}$ $\nu f_{7/2}^{8}$) and ($\pi f_{7/2}^{7}$ $\nu f_{7/2}^{7}$) configurations are assumed for the ground state of ^{54}Fe and for the ground state (0^+) and the 0.94-MeV state (1^+) of ^{54}Co, respectively. The DWBA curves for the 5.32 and 10.23-MeV states are calculated for the pure $(\pi f_{5/2}\pi f_{7/2}^{6}\ \nu f_{7/2}^{7})_{1^+}$ configuration. The DWBA calculations reproduce very well not only the angular distribution shapes but also the magnitudes of cross sections for the ground state and the 0.94-MeV state. The calculated angular distribution shapes for the 5.32- and 10.23-MeV states are also in good agreement with the measurements, supporting the 1^+ assignments to these states.

The (p,n) cross sections for these states may be compared with the β-decay matrix elements. In the present experiment the momentum transfer q, 0.12 fm^{-1} for the IAS and 0.20 fm^{-1} for the 10.23-MeV state at 15.2°, is small enough to allow such a comparison. Also the effects of tensor and LS terms in the effective interaction are expected to be small for such small q, and indeed DWBA calculations corroborate such a presumption. The effects of distortion and exchange knock-out contribution are taken care of in the DWBA calculations, and the following arguments are subject only to the strengths V_τ and $V_{\sigma\tau}$ in the assumed effective interaction.

The log ft value of the $^{54}\mathrm{Co}(0^+) \rightarrow {}^{54}\mathrm{Fe}(0^+)$ β-decay is known to be 3.5. This value is almost identical to 3.49, which is expected for the pure $(\pi f_{7/2}^{7}\ \nu f_{7/2}^{7})_{01} \rightarrow (\pi f_{7/2}^{6}\ \nu f_{7/2}^{8})_{01}$ transition. This is in good agreement with the present analysis, in which 100 % of the observed (p,n) strength for the ^{54}Fe (g.s.) ^{54}Co(g.s.) transition is explained by the DWBA calculation. The measured cross section of the 10.23-MeV state is about 40 % of the calculated total $T_>$ GT strength. Assuming the 5.32-MeV state to be the T=0, 1^+ state arising from the $(\pi f_{5/2} \pi f_{7/2}{}^{6}\ \nu f_{7/2}{}^{7})$ configuration, we find it carries about 50 % of the $\nu f_{7/2} \rightarrow \pi f_{5/2}$ $T_<$ GT strength. The shell-model calculation of Gaarde et al. predicts a T=1 1^+ state at 10.7 MeV in ^{54}Co with a GT strength of $(ft)^{-1} = 8.8 \times 10^{-4}$, or about 50 % of the total $T_>$ GT strength. A T=0 1^+ state is also predicted in their calculation at about 6.7 MeV, with a T GT strength of $(ft)^{-1} = 4.2 \times 10^{-4}$, or about 32 % of the $\nu f_{7/2} \rightarrow \pi f_{5/2}$ $T_<$ GT strength. Thus the shell-model calculation is at least in qualitative agreement with the present results. The reduction of the GT strength observed here is similar to the ^{48}Sc and ^{90}Nb results and also to the quenched M1 strengths reported for various medium and heavy nuclei.

In conclusion, we observed a peak at an excitation energy of 10.23 MeV in the ^{54}Fe(p,n)^{54}Co reaction. The width of this peak is 95±30 keV, and its angular distribution strongly suggests a 1^+ assignment. We interpret this state as the T=1 1^+ state, which carries about 40 % of the expected $T_>$ GT strength. Another peak at E_x = 5.32 MeV is also assigned as 1^+, and interpreted as the $T_<$ GT state. The energies and the strengths of these states are in agreement with the shell-model calculation of Gaarde et al.

We are grateful to Professor S. Morita for his support to this work. We would like to acknowledge the staff of Cyclotron and Radioisotope Center for their assistance during the running of this experiment. We are indebted to Professor H. Horie, Dr. K. Muto and Mr. M. Hino for many theoretical discussions.

References

1) D. E. Bainum, J. Rapaport, C. D. Goodman, D. J. Horen, C. C. Foster, M. B. Greenfield, and C. A. Goulding, Phys. Rev. Lett. 44, 1751 (1980).
2) B. D. Anderson, J. N. Knudson, P. C. Tandy, J. W. Watson, R. Madey, and C. C. Foster, Phys. Rev. Lett. 45, 699 (1980).
3) C. Gaarde, J. S. Larsen, M. N. Harakeh, S. Y. van der Werf, M. Igarashi, and A Müller-Arnke, Nucl. Phys. A334, 248 (1980).
4) C. Gaarde, J. S. Larsen, A. G. Drentje, M. N. Harakeh, S. Y. van der Werf, and A. Müller-Arnke, Nucl. Phys. A346, 497 (1980); M. N. Harakeh, private communication.
5) H. Orihara and T. Murakami, to be published.
6) R. Schaeffer and J. Raynal, Saclay Report NO CEA-R-4000, 1970.
7) Sam M. Austin, in The (p,n) Reaction and the Nucleon-Nucleon Force, edited by C. D. Goodman et al. (Plenum, New York, 1980), p. 203.
8) R. R. Doering, D. M. Patterson, and Aaron Galonsky, Phys. Rev. C 12, 378 (1975).
9) F. D. Becchetti, Jr., and G. W. Greenlees, Phys. Rev. 182, 1190 (1969).
10) J. D. Carlson, C. D. Zafiratos, and D. A. Lind, Nucl. Phys. A249, 29 (1975).

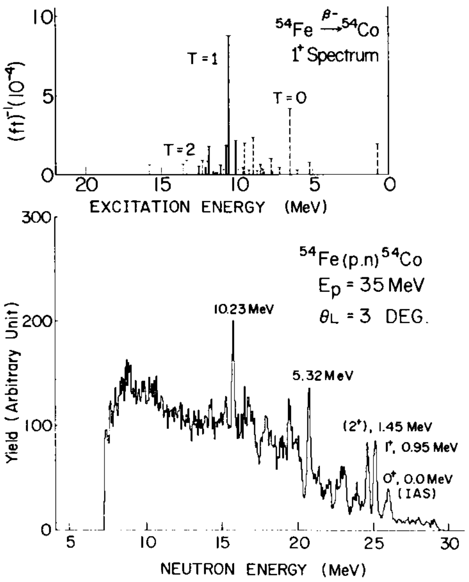

Fig. 1. Neutron energy spectrum for the ^{54}Fe(p,n)^{54}Co reaction at θ_{lab} = 3° measured at a neutron flight-path of 24. 6 m. Energy per bin is 50 keV. Also shown is the theoretical prediction for the locations and strengths of 1^+ states by Gaarde et al. (Ref. 4).

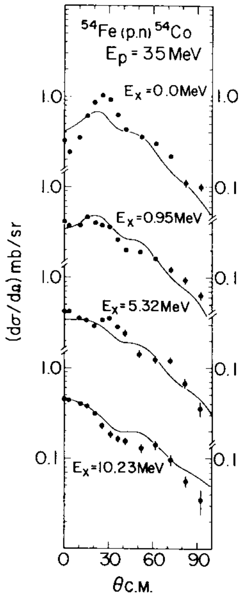

Fig. 2. Differential cross sections for the peaks corresponding to the ground state, and the 0.94-, 5.32- and 10.23-MeV states in ^{54}Co. The lines are DWBA predictions calculated with 1.0-fm-range Yukawa forces.