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Marked progress has been made during the last decades towards the understanding of the relationship between the beta-decay and (p,n) reaction by exploring the Gamow-Teller (GT) strength function in both experiment and theory. In this course, the "classical" quenching phenomena in beta-decay strength, which was interpreted by for example Ikeda et al. [1] as the result of spreading of its strength up to higher excitation region by strong repulsive particle-hole interactions, have been investigated experimentally by the (p,n) reaction. Whilst the higher-lying Gamow-Teller strengths have been indeed confirmed [2] as the Gamow-Teller giant resonance (GTGR), a new type of quenching for transition strength was observed [3,4]. In this "modern" quenching phenomena, the (p,n) strengths for GTGR in heavier nuclei are quenched when they are compared with the sum-rule limit value of *3 (N-Z)* model independently. Alternatively in lighter nuclei, the GT transitions to isolated states are quenched as well [4], when we compare the (p,n) cross sections with those calculated with sophisticated shell-models. Recent compilation by Brown and Wildenthal for the beta-decay strengths in sd-shell nuclei [5] shows that the renormalization factor is needed, even for beta-decays, to fit the experimental strengths by the theory with *free nucleon* values.

The "missing" GT strength has presented a challenging problem to nuclear theories, and explanation in teams of core polarization, mesonic effects, Δ-excitation, etc., have been explored. Calcium isotopes have provided a good place to investigate spin-isospin excitations in nuclei due to their simple shell structure, and to a variety of isotopes ^{42}Ca through ^{48}Ca with extra neutrons filling the $f_{7/2}$ shell. Extensive studies with calcium isotopes by proton scattering [7], charge exchange (p,n) reaction [8,9] and large angle electron scattering [10] experiments have so far been carried out. Among the calcium isotopes, ^{42}Ca plays a unique role [11], since the ground state of ^{42}Ca belong to the member of SU(4) symmetry of L = 0, S = 0 and T = 1 rather than the pure $(f_{7/2})^2{}_{J=0}$ configuration. The operation of the GT operator, $\sum \sigma\tau_-$, on the SU(4) symmetry state should yield only the L = 0, S = 1 and T = 0 state, and yields no strong transition to J = 1 state with the $(f_{5/2},f_{7/2})$ configuration.

Thus, the ^{42}Ca(p,n)^{42}Sc reaction is an excellent candidate to study the missing GT strength less model dependently by observing the low-lying isolated state in stead of observing high-lying GTGR in heavier nuclei, which is suffer from the difficulties of background subtraction. In this report, we discuss the (p,n) reactions on ^{42}Ca and ^{44}Ca focussing our attention on the $0^+ \rightarrow 1^+$ GT-type transitions. As for the ^{44}Ca(p,n)^{44}Sc reaction, we have previously reported [9] its medium resolution data with preliminary analysis.

The experiment was performed at the Cyclotron and Radioisotope Center, Tohoku University with a 35-MeV proton beam from an AVF-cyclotron and a beam swinger system. The details of the experimental setup have been described previously [12]. Neutron energies were measured by the time-of-flight technique (TOF), where neutrons were detected by a detector array located at 44 m from the target. The detector were filled with organic liquid scintillator NE213 of 20.7 l in a total sensitive volume. The absolute efficiencies of the detector were obtained from the ^{7}Li(p,n)^{7}Be activation analyses with an error less than ± 6%, while Errors in absolute magnitude of cross sections were estimated to be less than 12%. The self-supporting targets of metallic calcium isotopes were used. Their thicknesses and enrichments were, respectively, 1.82 and 2.30 mg/cm^2, and 98.0 and 98.7 % for ^{42}Ca and ^{44}Ca.

Figure 1 shows the excitation energy spectrum of neutrons measured for the ^{42}Ca(p,n)^{42}Sc reaction at a laboratory angle of 25 °. The spectrum is dominated by the analog transition leading to the ground state, and the $0^+ \rightarrow 1^+$ transition to the 0.611 MeV state in ^{42}Sc, corresponding to the F (Fermi) and GT transitions, respectively. It should be noted in the neutron spectrum that no prominent peaks are seen in the excitation energy region around 10 MeV, where the T = 1, 1^+ states with the predominant $(\pi f_{5/2},\nu f_{7/2}^{-1})$ configuration are expected from the view point of shell model in stead of SU(4). Peaks at $E_x \sim 10$ MeV are due to the ^{16}O contamination in the target. Neutron spectrum for the ^{44}Ca(p,n)^{44}Sc reaction is illustrated in Fig. 2 together with peak fitting results. Similarly, the prominent peak is neutrons leading to the isobaric analog state at $E_x = 2.785$ MeV in ^{44}Sc, while the most dominant GT-transition to the $T_<$ (=1) 1^+ state at 0.667 MeV is rather weakly populated. As discussed later on, the GT strength, suggested theoretically to concentrate to this state, seems to be scattered over several states in $3 < E_x < 4$ MeV.

In Fig. 3, angular distributions of the ^{42}Ca(p,n) differential cross sections are shown for the transitions to the ground- and 1^+, 0.611 MeV-states, both of which show a typical L = 0 angular distribution shape with the present conditions. Curves in figures are the macroscopic (for g.s.; IAS) and microscopic (0.611 MeV; 1^+) distorted-wave Born-approximation predictions. Theoretical cross sections are normalyzed to the experimental ones by a factor indicated as "N" in the figure to optimize fitting.

In order to analyze the (p,n) reactions on ^{42,44}Ca based on the DWBA theory, we have employ the codes DWUCK-4 by Kunz [13)] and DWBA-74 by Shaeffer and Raynal [14)] for the macroscopic and microscopic analyses, respectively. Optical potential parameters of Becchetti and Greenlees [15)] were used for protons, while those for neutrons were self-consistent potential parameters derived by Carlson et al. [16)]. As for the microscopic DWBA analysis, a Wood-Saxon type bound state potential with r_0 = 1.25 fm, a = 0.65 fm and V_{LS} = 6 MeV, and the depth adjusted to reproduce the binding energy of a proton or neutron was used to generate the radial dependence of the transition density. Spectroscopic amplitudes namely one-body-transition density (OBTD) calculated in a framework of the shell model by Mutoh [17)] have been employed in the present analysis. Effective nucleon-nucleon interaction by Bertsch et al. [18)] (M3Y) was used in the calculation. Reliability of the information extracted from such DWBA analyses was discussed in detail by Ohnuma et al. [19)].

Breaking of the SU(4) symmetry may yield fragmentation of the GT-strength over several states, while the theory in ref. 17 predicts that 72 % of the GT-strength concentrate on the 1^+, 0.611 MeV-state, and that 18 % on a high-lying T = 1,1^+ state, its main component being ($\pi f_{5/2}, \nu f_{7/2}^{-1}$). The experimental evidence, however, shows that no significant GT-fractions are shared among other transitions except for that to the 1^+, 0.611 MeV-state, though we need a renormalization factor of 0.4 (N in fig. 2) to optimize the DWBA comparison. It should be noted that this factor is rather small comparing with that for the beta-decay, where this factor is evaluated to be 2.67/4.03 = 0.62, from the *log ft* value of 3.17 compiled for the ^{42}Ti (β^+) ^{42}Sc (1^+, 0.611 MeV) decay [20)].

In the case of the ^{44}Ca(p,n)^{44}Sc reaction, the theory predicts only 12 % of the total GT-strength being concentrated on the 1^+, 0.667 MeV-state, while it predicts a strong transition to a 1^+ state at E_x = 3.9 MeV having a B(GT) value of 3.0, which means 25 % of the total strength of *3(N-Z)*. The presently observed (p,n) strength leading to the 0.667 MeV-state is reasonably reproduced with N = 0.7 by the DWBA calculations using the spectroscopic amplitudes described above, whereas no significant peaks have been found in the predicted excitation energy region, but instead four candidates for the 1^+ states are found in $E_x \sim$ 3 - 4 MeV.

References

1) Ikeda K., Fujii S. and Fujita J. I., Phys. Lett. **3** (1963) 271.
2) Doering R. R. et al., Phys. Rev. Lett. **35** (1975) 1691.
3) Goodman C. D. et al., Phys. Rev. Lett. **44** (1980) 1755.
4) Orihara H. et al., Phys. Rev. Lett. **47** (1981) 301.
5) Furukawa K. et al., Phys. Rev. C. **36** (1987) 1686.
6) Brown B. A. and Wildenthal B. H., At. Data and Nucl. Data Tables **33** (1985) 347.
7) Crawley G. M. et al., *Spin Excitation in Nuclei* ed. Goodman C. D. et al. (Plenum, 1984).
8) Goodman C. D. et al., Phys. Lett., **107B** (1981) 406.
9) Orihara H. et al., CYRIC Annual Report (1983).
10) Steffen W. et al., Phys. Lett. **95B** (1980) 23.
11) Toki H. and Bertsch G. F., Phys. Rev. C **26** (1982) 2330.
12) Orihara H. et al., Nucl. Instrum. and Methods **A257** (1987) 189.
13) Kuntz P. D., The code Dwuck-4, unpublished.
14) Shaeffer R. and Raynal J., CEA R4000,1970.
15) Becchetti Jr F. D. and Greenlees G. W. Phys. Rev. **192** (1969) 1190.
16) Carlson D., Zafiratos C. D. and Lind D. A. Nucl. Phys. **A249** (1975) 29.
17) Mutoh K., private communication.
18) Bertsch G. et al., Nucl. Phys. **A284** (1977) 399.
19) Ohnuma H. et al., Nucl. Phys. **A467** (1987) 61.
20) Endt P. M. and Van der Leun C. Nucl. Phys. **A310** (1978) 1.

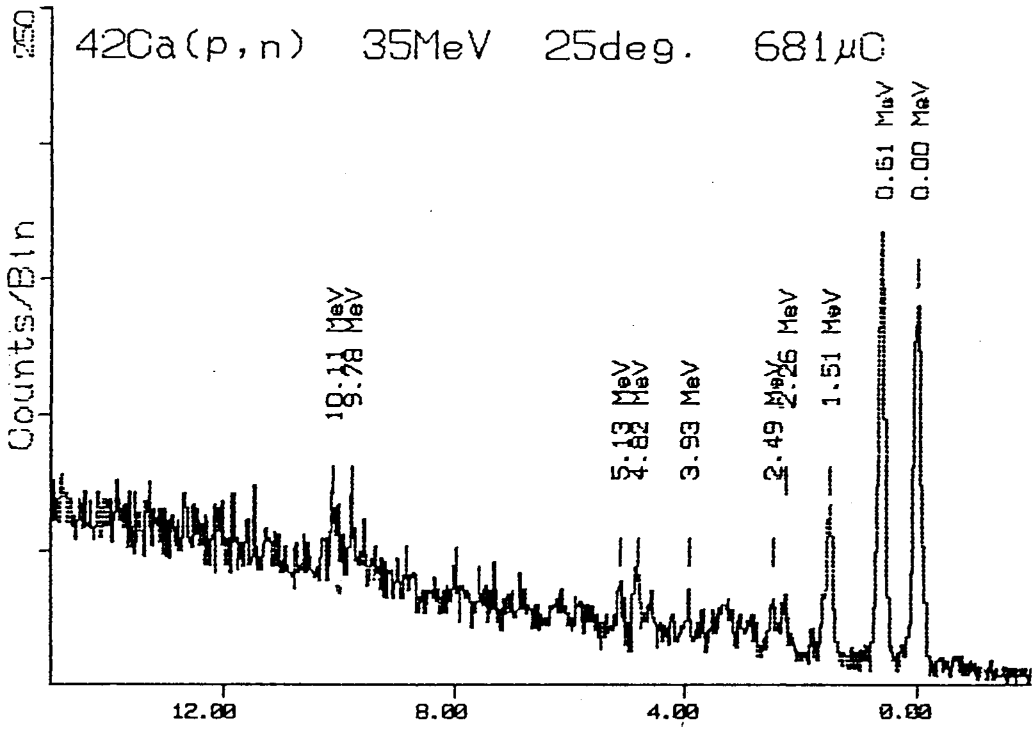

Fig. 1 Excitation energy neutron spectrum taken for the ^{42}Ca(p,n)^{42}Sc reaction at 25• (lab.) with a 44 m long neutron flight path. Energy per bin is 25 keV.

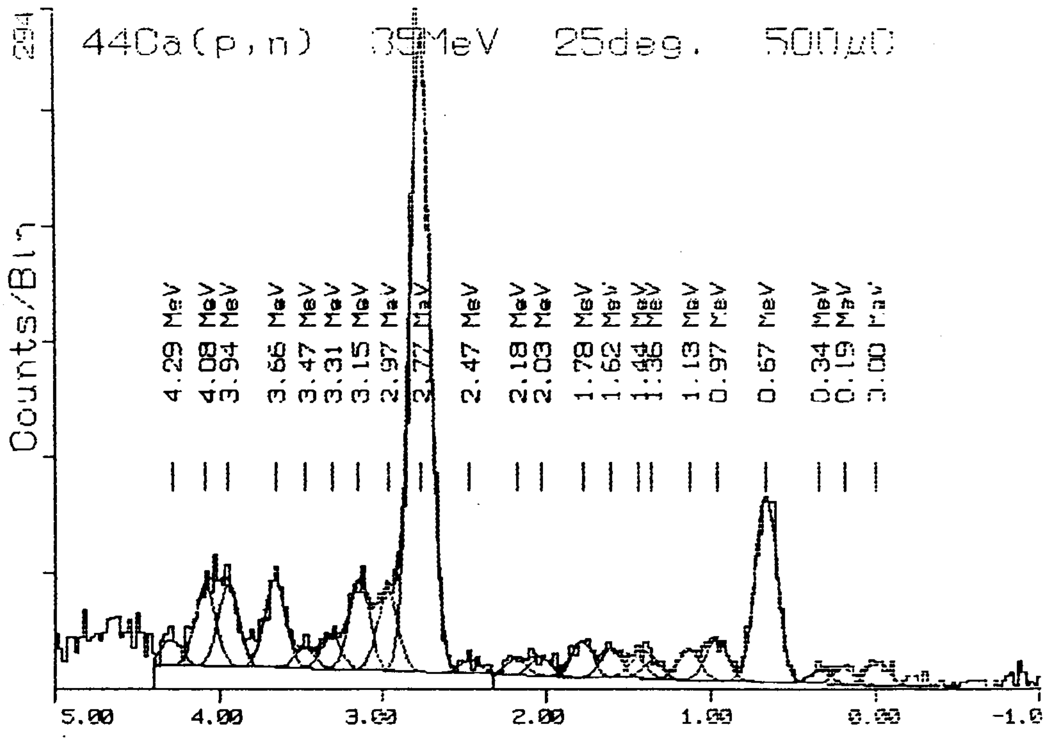

Fig. 2. Fig. 1 Excitation energy neutron spectrum taken for the ^{42}Ca(p,n)^{42}Sc reaction at 25• (lab.) with a 44 m long neutron flight path. Energy per bin is 25 keV. Solid curves in the figure are results of peak fitting analyses.

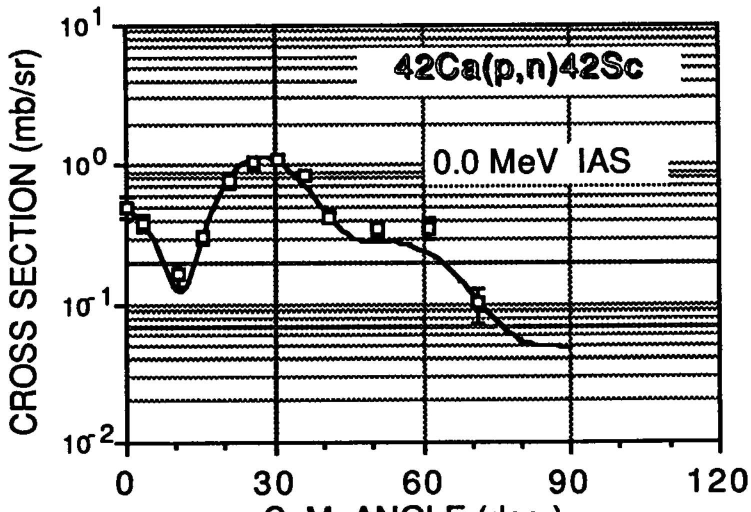

Fig. 3. Differential cross sections for neutrons leading to the ground state in ^{42}Sc. The curve is a DWBA comparison described in text. N in the figure is normalization factor introduced to optimize fitting.

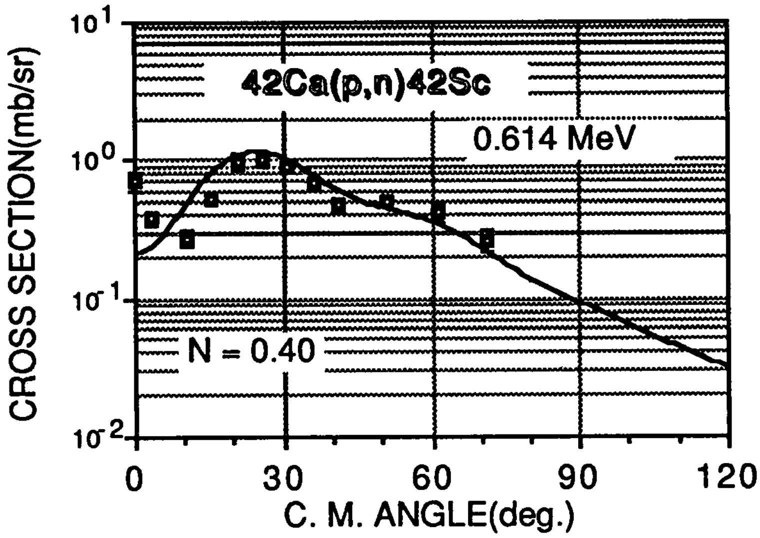

Fig. 4. Same with Fig. 3. but for the transition leading to the 0.611-MeV, 1^{+} state.