Determination of Gamow–Teller unit cross sections of the \((p, n)\) reaction at 200 and 300 MeV

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Abstract. The Gamow-Teller (GT) unit cross section, \(\hat{\sigma}_{GT}\), is an essential quantity to deduce the GT transition strength, \(B(GT)\), from the \((p, n)\) \(0^+\) cross section. \((p, n)\) measurements at 200 and 300 MeV were performed using the Neutron Time-of-Flight (NTOF) facility at the Research Center for Nuclear Physics (RCNP). The \(\hat{\sigma}_{GT}\) values were determined, for the first time, for several nuclei in the region of \(A > 50\) at \(E_p = 200\) and 300 MeV. A significant difference between the \(B(GT)\) values obtained by \((p, n)\) and \((3\text{He}, t)\) measurements was found.

Charge exchange reaction is a powerful tool for the study of Gamow-Teller (GT) transitions. Especially, in \((p, n)\) or \((n, p)\) measurements at 0 degrees, Taddeucci et al. have established a proportionality relation between the differential cross section and the GT transition strength, \(B(GT)\), as \(\frac{d\sigma}{d\Omega}(0^+) = \hat{\sigma}_{GT} F(q, \omega) B(GT)\) \cite{1}. Here, \(F(q, \omega)\) is a kinematic correction factor obtained by distorted wave impulse approximation (DWIA) calculations and \(\hat{\sigma}_{GT}\) is the proportionality constant, so-called GT unit cross section. Therefore the GT unit cross section is an essential quantity to deduce \(B(GT)\) values. We determined the \(\hat{\sigma}_{GT}\) values at the incident energy \(E_p = 200\) and 300 MeV for several nuclei whose mass numbers, \(A\), are larger than 50.

The \((p, n)\) measurements at 200 and 300 MeV were performed at the NTOF facility \cite{2}. Enriched \(^{58}\)Ni, \(^{118}\)Sn and \(^{120}\)Sn targets were used and their thicknesses were \(99 \pm 3\) mg/cm\(^2\), \(100 \pm 3\) mg/cm\(^2\) and \(170 \pm 5\) mg/cm\(^2\), respectively. The neutron flight path length was about 100 m. The scattered neutrons were detected by a newly developed neutron detection system, NPOL3 \cite{3}, with a high time resolution of about 200 ps. An enriched \(^{7}\)Li target with a thickness of 2.617 mm was used to determine the neutron detection efficiency of NPOL3 based on the known differential cross section of \(^{7}\)Li\((p, n)^{7}\text{Be}(gnd + 0.43\) MeV) reaction \cite{4}.

Figure 1 shows the double differential cross section spectrum for the \(^{58}\text{Ni}(p, n)^{58}\text{Cu}(0^+)\) reaction at 300 MeV. The differential cross section for the ground \(1^+\) state was derived by peak fitting where the peak energies were taken from the precise \((3\text{He}, t)\) spectrum \cite{5}. The result is
shown in Fig. 1 as an inset. The $\sigma_{GT}$ value was derived by using the $B(GT)$ value obtained by beta decay experiments. The $\sigma_{GT}$ values of $^{118}$Sn and $^{120}$Sn were obtained similarly.

The obtained $\sigma_{GT}$ values are shown as a function of $A$ in Fig. 2. The error bar of each data point is the quadratic sum of the statistical error and the systematic ones specific to the target nuclei which include the uncertainties by the $B(GT)$ value ($\pm 0.6\%$, $\pm 2.9\%$ and $\pm 2.3\%$ for $^{58}$Ni, $^{118}$Sn and $^{120}$Sn, respectively) and the effect of the $^{120}$Sn contaminant in the $^{118}$Sn target ($\pm 1.2\%$). The error bar shown in the lower-right corner of the each panel indicates the quadratic sum of the other systematic uncertainties mainly due to the target thickness ($\pm 3\%$), the $^7$Li target thickness ($\pm 3\%$), and the integrated current ($\pm 2\%$). The $A$-dependences of $\sigma_{GT}$ were derived by fitting the data. Here, $\sigma_{GT}$ is assumed to be proportional to $\exp(-x \times A^{1/3})$ neglecting the nuclear structure effect of individual nuclei.

$\sigma_{GT}$ values estimated by the present $A$-dependences have important consequences. For example, Yako et al. have derived a GT quenching factor [6] by using the $\sigma_{GT}$ value of $3.59 \pm 0.18$ mb/sr deduced from the $A$-dependence is used. The error denoted here is the quadratic sum of the fitting error and the other systematic errors mentioned above.

Assuming the proportionality relation, the $B(GT)$ values for the GT transition of $^{58}$Ni($g_{nd}$) $\rightarrow$ $^{58}$Cu(1.051 MeV) can be deduced as $0.406 \pm 0.036$ and $0.414 \pm 0.006$ from the ($p,n$) cross sections at 200 and 300 MeV, respectively. On the other hand, the $B(GT)$ value deduced by the ($^3$He, $t$) measurement at $E_{^3He} = 450$ MeV [5] is reported as $0.265\pm 0.013$ which is significantly smaller than those of the ($p,n$) measurements. This discrepancy may cast a serious question on the proportionality relation.

In summary, the $\sigma_{GT}$ values were determined for the ($p,n$) reactions on $^{58}$Ni, $^{118}$Sn and $^{120}$Sn at 200 and 300 MeV. The $A$-dependences of $\sigma_{GT}$ were derived. The $B(GT)$ value deduced by the ($p,n$) measurement on $^{58}$Ni disagrees with that deduced by the ($^3$He, $t$) measurement, which may raise a question on the proportionality relation of these reactions.

References
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