Isoscalar and Orbital Contribution in $M1$ Transitions of ^{54}Fe

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The $\Delta L=0, \Delta S=1$ states observed in inelastic scatterings are called $M1$ states. To observe $M1$ states, (e,e') and (p,p') reactions are used. If experimental conditions are selected, corresponding $M1$ states are observed; in the (e,e') in the backward angle experiments, while in the (p,p') in the 0° experiment at intermediate incident energies. The electro-magnetic $M1$ operator, which works in the (e,e'), contains ℓ, σ, $\ell\tau$ and $\sigma\tau$ terms. On the other hand, in the (p,p') reactions $\sigma\tau$ operator is dominant in the excitation of $M1$ states.

Isospin quantum number of the ^{54}Fe ground state is $T_0=1$. In the $^{54}\mathrm{Fe}(e,e')$ reaction, if the isospin number of the excited state is $T=1$, all terms of the $M1$ operator contribute in the $M1$ transition. If that of the excited state is $T=2$, $\ell\tau$ and $\sigma\tau$ terms contribute. On the other hand, in the $^{54}\mathrm{Fe}(p,p')$ reaction, the contribution of the $\sigma\tau$ term is dominant. Transition strengths observed in the $^{54}\mathrm{Fe}(e,e')$ and $^{54}\mathrm{Fe}(p,p')$ reactions can be different due to the different characteristics of active operators.

Since the coefficient for the IV spin term is the largest in a usual case, the reduced $M1$ transition strength studied in electron scattering, i.e., $B(M1)$, can be written [1, 2],

$$B(M1) \quad \propto \quad \left(g_s^{\mathrm{IV}} M(\sigma\tau)\right)^2 \left| \, 1 + \frac{g_\ell^{\mathrm{IV}} M(\ell\tau) - g^{\mathrm{IS}} M'(\mathrm{IS})}{g_s^{\mathrm{IV}} M(\sigma\tau)} \, \right|^2. \tag{1}$$

where the value $|\, 1+\{g_\ell^{\mathrm{IV}} M(\ell\tau) - g^{\mathrm{IS}} M'(\mathrm{IS})\}/g_s^{\mathrm{IV}} M(\sigma\tau)\, |^2$ in Eq. (1) can be larger or smaller than unity depending on the constructive or destructive contributions of the IS and $\ell\tau$ terms.

On the other hand, the reduced transition strength $B_{\mathrm{IE}}(M1)$ in the (p,p') consists of only $\sigma\tau$ matrix element. Following the definition of the $B(GT)$ value for the Gamow-Teller transition, we define $B_{\mathrm{IE}}(M1)$ as [1],

$$B_{\mathrm{IE}}(M1) \quad = \quad \frac{1}{2J_i+1}\frac{1}{2}\frac{C_{M1}^2}{2T_f+1}[M(\sigma\tau)]^2. \tag{2}$$

Since in Eqs. (1) and (2), the $M(\sigma\tau)$ is common, the IS and IV orbital contributions can be discussed by comparing $B(M1)$ and $B_{\mathrm{IE}}(M1)$.

The $B(M1)$ strength distribution from $^{54}\mathrm{Fe}(e,e')$ reaction [4 and $^{54}\mathrm{Fe}(p,p')$ experiment spectrum at 0° performed at IUCF [4] are shown in Figs. 1(a) and (b), respectively. By comparing these two figures, corresponding $M1$ states are identified in the region of $E_x = 8.0 \sim 12.0$ MeV. The $B_{\mathrm{IE}}(M1)$ value for each state observed in the (p,p') was determined using the 0° cross section.

In order to study the contributions of IS and IV orbital terms interfering with the IV spin term in the $B(M1)$ value, we introduce a ratio [2]

$$R_{\mathrm{ISO}} = \frac{B(M1)}{B_{\mathrm{IE}}(M1)}. \tag{3}$$