Spin and Orbital Contributions for $M1$ Transitions in ^{23}Na (I)

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The magnetic dipole ($M1$) operator for $M1$ γ-transitions and the Gamow-Teller (GT) operator for GT β-decays are similar in that they have the same major component, i.e., the isovector (IV) spin ($\sigma\tau$) term, although transitions originate from the electromagnetic and weak interactions, respectively [1, 2]. The difference of them is that the electromagnetic $M1$ operator contains not only the $\sigma\tau$ term, but also IV orbital ($\ell\tau$), isoscalar (IS) spin (σ), and IS orbital (ℓ) terms [3, 4]. If the $\sigma\tau$ term in the $M1$ transition is dominant, similar transition strengths are expected for the corresponding $M1$ and GT transitions. The "quasi" proportionality between $B(\mathrm{GT})$ and $B(M1)$ is expressed as [4]

$$B(M1) \approx \frac{3}{8\pi}(g_s^{\mathrm{IV}})^2\mu_N^2\frac{C_{M1}^2}{C_{\mathrm{GT}}^2}R_{\mathrm{MEC}}B(\mathrm{GT}) = 2.644\mu_N^2\frac{C_{M1}^2}{C_{\mathrm{GT}}^2}R_{\mathrm{MEC}}B(\mathrm{GT}). \tag{1}$$

where the different contributions of the so-called meson exchange currents (MEC) to the $M1$ and GT operators [5, 6] has been shown by the ratio R_{MEC} [7], whose most probable value is deduced to be 1.25 for the nuclei in the middle of *sd* shell [4]. From Eq. (1), we find that a renormalized $B(M1)$ values defined by

$$B^R(M1) = \frac{2}{2.644\mu_N^2}B(M1), \quad \text{for } T_f = 1/2 \tag{2}$$

can be compared directly with the values of $B(\mathrm{GT})$.

Under the assumption that isospin is a good quantum number, isobaric analog structure is expected in a pair of $T = 1/2$ mirror nuclei, and thus analogous transitions are found. For the $M1$ transitions in the deformed mirror nuclei pair ^{23}Na-^{23}Mg, the contributions of these various terms are studied by comparing the strengths of the $M1$ γ transitions in ^{23}Na and the Gamow-Teller transitions studied in the high resolution $^{23}\mathrm{Na}(^3\mathrm{He},t)^{23}\mathrm{Mg}$ reaction (see the previous article). They are analogous each other. The $B(M1)$ values in ^{23}Na were calculated using the data complied in Ref. [8]. The distribution of them is given in terms of $B^R(M1)$ in Fig. 1(b) and is compared to the $B(\mathrm{GT})$ distribution obtained from high-resolution $^{23}\mathrm{Na}(^3\mathrm{He},t)^{23}\mathrm{Mg}$ charge-exchange measurements shown in Fig. 1(a).

In order to examine the interference of IS and IV orbital terms with the IV spin term in an $M1$ transition, we define the ratio [9]

$$R_{\mathrm{ISO}} = \frac{1}{R_{\mathrm{MEC}}}\frac{B^R(M1)}{B(\mathrm{GT})}. \tag{3}$$

By its definition, $R_{\mathrm{ISO}} > 1$ usually shows that the former two terms are constructive to the IV spin term, while $R_{\mathrm{ISO}} < 1$ usually shows a destructive contribution.

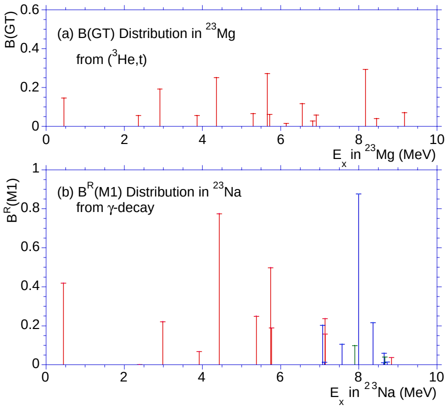

Figure 1: Comparison of $B(\mathrm{GT})$ and $B^R(M1)$ strength distributions. (a) $B(\mathrm{GT})$ strength distribution from the present ^{23}Na(^{3}He,t)^{23}Mg reaction. (b) $B^R(M1)$ strength distribution deduced from the γ-transition data. For the definition of $B^R(M1)$, see text.

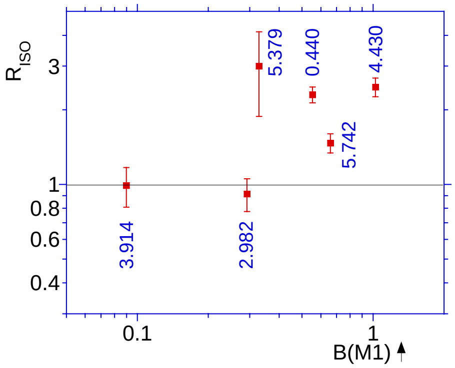

Figure 2: The ratio R_{ISO} for $M1$ transitions in ^{23}Na. The ratio is sensitive to the combined contribution of IS term and IV orbital term to each $M1$ transition. Values of $R_{\mathrm{ISO}} > 1 (< 1)$ suggest constructive (destructive) interference of these terms with the IV spin term. For the definition of R_{ISO}, see text.

The R_{ISO} values are shown as a function of $B(M1)\uparrow$ in Fig. 2. It is observed that R_{ISO} values are large for strong transitions, suggesting that the combined IS and orbital contribution is large in stronger transitions. This was quite different in the ^{27}Al-^{27}Si pair, where the R_{ISO} values became almost unity when the transitions become stronger and $B(M1)\uparrow$ exceeds 0.1 (see Fig. 4 of Ref. [9]).

The g-factor for the IV spin term ($g_s^{\mathrm{IV}} = 4.706$) is about an order of magnitude larger than those of IS terms and IV orbital term. Therefore, if the reduced matrix element M for IS and IV orbital terms are of average strength, it is expected that the IV spin term becomes usually larger than the other terms and that R_{ISO} has a value not so much away from unity [1, 9]. It is clear this is not the case for the $M1$ transitions in ^{23}Na.

A peculiar mechanism to deformed nuclei which largely enhances the combined IS and orbital contributions for stronger transitions is needed to explain the behavior of R_{ISO} shown in Fig. 2.

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