Large Orbital Contribution for $M1$ Transitions in Deformed Nucleus ^{23}Na

Y. Shimbara[a], Y. Fujita[a], T. Adachi[a], G.P.A. Berg[b], H. Fujimura[b], H. Fujita[a], K. Hara[b],
K. Hatanaka[b], J. Kamiya[b], T. Kawabata[c], T. Noro[b], T. Shinada[a], H.P. Yoshida[b],
M. Yoshifuku[a] and M. Yosoi[b]

[a]*Dept. Phys., Osaka University, Toyonaka, Osaka 560-0043*
[b]*RCNP, Osaka Unibersity, Ibaraki, Osaka 567-0047*
[c] *Dept. Phys., Kyoto University, Sakyo, Kyoto 606-8224*

The deformation δ makes the contribution of orbital term large in $M1$ transition strength [1]. In order to study the effect of the deformation in the $M1$ transitions in ^{23}Na, experimental data on $M1$ transiton strengths obtained from γ-decay in ^{23}Na and analogous GT transiton strengths obtained from good-resolution $^{23}\mathrm{Na}(^3\mathrm{He},t)^{23}\mathrm{Mg}$ reactions at 150 MeV/nucleon and at 0° have been compared.

A pair of isospin $T = 1/2$ mirror nuclei is characterized by $T_z = \pm 1/2$. As a result of the analogous nature of corresponding sates in the mirror nuclei, corresponding $M1$ and GT transitions are analogous.

$M1$ operator contains not only the usually dominant isovector (IV) spin ($\sigma\tau$) term, but also IV orbital ($\ell\tau$), isoscalar (IS) spin (σ) and orbital (ℓ) terms. On the other hand, Gamow-Teller (GT) transitions are caused only by the $\sigma\tau$ term [2]. The IV spin-type matrix element is common in both transitions. The difference of strengths of corresonding $M1$ and GT transitions are caused by IS spin term and orbital terms in the $M1$ transition.

In order to see how the IS and orbital terms contribute to an $M1$ transition, we define the ratio [2],

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

where C_{M1} and C_{GT} are the isospin Clebsch-Gordan (CG) coefficients $C_{M1} = (T_i T_{zi} 10 | T_f T_{zf})$ and $(T_i T_{zi} 1 \pm 1 | T_f T_{zf})$, respectively. The difference of MEC contributions to the $M1$ and GT operators are expressed by the ratio, $R_{\mathrm{MEC}} = [M_{M1}(\sigma\tau)]^2/[M_{\mathrm{GT}}(\sigma\tau)]^2$, where the $M_{M1}(\sigma\tau)$ and $M_{\mathrm{GT}}(\sigma\tau)$ are matrix elements defined by $\langle J_f T_f ||| \sum_{j=1}^{A} \sigma_j \tau_j ||| J_i T_i \rangle$. R_{MEC} has the value of about 1.25 in sd-shell nuclei [3]. $R_{\mathrm{ISO}} > 1$ and < 1 show the constructive and destructive contributions of IS and orbital terms.

At intermediate energies ($\geq$ 100 MeV/nucleon) and at small momentum transfer q, the $\sigma\tau$ term of the effective nuclear interaction becomes dominant [4]. It is known that in (p,n) reactions at 0°, the cross section for a GT transition is approximately proportional to $B(\mathrm{GT})$. Recently the proportionality has been also established for the $(^3\mathrm{He},t)$ reactions at 150 MeV/nucleion and at 0° [2].

In order to map $B(\mathrm{GT})$ to higher excitation energies, $^{23}\mathrm{Na}(^3\mathrm{He},t)$ experiment was performed. A 150 MeV/nucleon ^{3}He beam from the Ring Cyclotron at RCNP was used to bombard thin ^{23}Na target foils. The Grand Raiden spectrometer [5] set at 0° was used for momentum analysis. Fine structure was observed up to $E_x \approx 10$ MeV in ^{23}Mg.

For each excited state in ^{23}Na, the $M1$ γ-transition strength $B(M1)$ (in units of μ_N^2) to the ground state is calculated using the data compiled by Endt [6]. In order to compare values of $B(M1)$ and $B(\mathrm{GT})$ directly for the analogous transitions, $B(M1)$ need following modifications: 1) the $B(M1)$ values are divided by the numerical factor $2.643\mu_N^2$ for the conversion of different coupling constants (different units) in $M1$ and GT transitions, and 2) these values

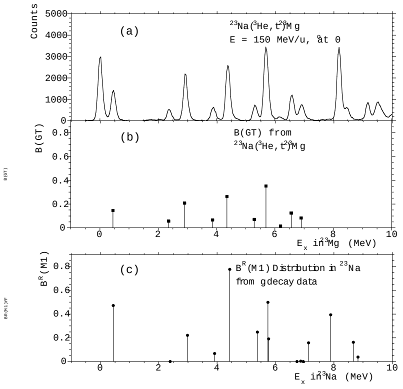

Figure 1: The ^{23}Na(^{3}He, t) spectrum at 0°, and comparison of the B(GT) strength distribution derived from the ^{23}Na(^{3}He, t) reaction and the $B^R(M1)$ distribution deduced from the measurements of γ transitions in ^{23}Na.

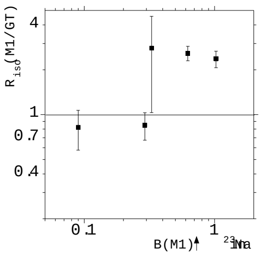

Figure 2: The ratio $R_{\rm ISO}$ showing IS and IV orbital contributions for transitions with various $B(M1)$ values in ^{23}Na.

are multiplied by a factor of 2 compensationg for the different isospin CG coefficients. We call the modified $B(M1)$ values to be compared to the B(GT) values $B^R(M1)$.

The B(GT) values from ^{23}Na(^{3}He, t)^{23}Mg and $B^R(M1)$ values from γ decay in ^{23}Na are compared in Fig. 1. The $R_{\rm ISO}$ values were calculated using Eq. (1). They are shown in Fig. 2 as a function of $B(M1)\uparrow$.

While Fig. 1 shows good correspondence of the excitation energies up to 6 MeV for the GT and M1 states in ^{23}Mg and ^{23}Na, strength distributions of B(GT) and $B^R(M1)$ are rather different. The $R_{\rm ISO}$ values shown in Fig. 2 are large even for rather strong transitions, indicating that the contributions of IS and/or orbital terms are large. Since the sontributions of IS and $\ell\tau$ terms are usually small for the $M1$ transitions in spherical nuclei, the $\sigma\tau$ term is dominant if the transition is strong, which leads to $R_{\rm ISO} \sim 1$. However, it is calculated that the orbital contributions increase in proportion to the deformation δ of a nucleus [1]. We expect that the large deformation $\delta \approx 0.4$ of ^{23}Na enhances the $M1$ transitions through the orbital term.

References

[1] I. Hamamoto and W. Nazarewicz, Phys. Lett. B297 (1992) 25.
[2] Y. Fujita *et al.*, Phys. Rev. C59 (1999) 90, and references there in.
[3] Y. Fujita. et al., Phys. Rev. C62 (2000) 044314-1
[4] W. G. Love and M. A. Franey, Phys. Rev. C **24** (1981) 1073.
[5] M. Fujiwara, et al., Nucl. Instr. and Meth. in Phys. Res. A 422 (1999) 484
[6] P. M. Endt, Nucl. Phys. A521 (1990)1; *ibid* A633 (1998)1, and references therein.