Position of the Gamow–Teller resonance and the problem of the reconstruction of the Wigner SU(4) symmetry

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Comparison of new experimental data with the energies of the Gamow–Teller resonance calculated from the theory of finite Fermi systems shows that the constants of the local isospin and spin–isospin interactions are approximately equal. This equality corresponds to the hypothesis of the reconstruction of broken SU(4) symmetry in the charged excitation branch.

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Recent experiments on the Gamow-Teller (spin-flip) resonance in the (p, n) reaction show that this resonance tends to approach an analog resonance with increasing mass number A and with increasing neutron excess N–Z (Refs. 1 and 2). We predicted this behavior of the Gamow-Teller resonance theoretically back in 1973-74 (Refs. 3 and 4) and attributed it to an effective suppression of the spin–orbit interaction by a spin–spin interaction, proportional to N–Z, in the charged pn channel. The consideration of this mechanism led us, in particular, to a first formulation of the hypothesis of the reconstruction of broken Wigner $\overline{\mathrm{SU}(4)}$ symmetry in heavy nuclei[3]; this hypothesis has recently been verified by a study of the mass relations of nuclei on the basis of this symmetry.[5]

It should be emphasized, however, that the SU(4) symmetry scheme should include, in addition to an effective suppression of the spin-orbit interaction in the charged channel, some additional relations among the constants of the effective quasiparticle interaction. In the theory of finite Fermi systems, for example, the SU(4)-invariant local interaction is

$$\Gamma^{\omega} = f_o + f_o' [\vec{\tau}_1 \vec{\tau}_2 + \vec{\sigma}_1 \vec{\sigma}_2 + (\vec{\tau}_1 \vec{\tau}_2)(\vec{\sigma}_1 \vec{\sigma}_2)] \qquad (1)$$

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so that the spin constant g_0, the isospin constant f'_0, and the spin-isospin constant g'_0 should obey

$$g_0 = f'_0 , \qquad g'_0 = f'_0 . \tag{2}$$

The discovery and experimental study of the Gamow-Teller resonance, which (like the analog resonance) corresponds to the charged excitation branch, gives us a way to determine whether the spin-orbit interaction is in fact suppressed with increasing $N-Z$ in the charged channel and also to determine how well the second relation in (2) holds. In the semiclassical model,[6] the position of the Gamow-Teller resonance with respect to the analog resonance is given by (for $\Delta\epsilon_F \geqslant 2E_{ls}$)

$$E_{\mathrm{GTR}} - E_{\mathrm{AR}} \approx (g'_0 - f'_0)\Delta\epsilon_F + \frac{2}{3}\,\frac{1+\frac{2}{3}g'_0}{g'_0}\,\frac{E_{ls}^2}{\Delta\epsilon_F}\,, \tag{3}$$

where $\Delta\epsilon_F \approx 4/3\ \epsilon_F N-Z/A$ is the energy width of the excess-neutron shell, and E_{ls} is the energy of the spin–orbit splitting averaged over these neutrons,

$$\bar{E}_{ls} \approx \frac{\sum\limits_{\lambda\lambda'}\left(E_{\lambda'}^{l-1/2} - E_{\lambda}^{l+1/2}\right) n_\lambda^n (1 - n_{\lambda'}^p)}{\sum\limits_{\lambda\lambda'} n_\lambda^n (1 - n_{\lambda'}^p)} \tag{4}$$

(n_λ^n and $n_{\lambda'}^p$ are the neutron and proton occupation numbers, and $E_{\lambda(\lambda')}^{l\pm 1/2}$ are the energies of the components of the spin-orbit doublets). The corrections for single-meson exchanges in (3) are small ($\Delta E_{\mathrm{GTR}}^{\pi,\rho} \sim 0.5-1.0$ MeV), since the Gamow-Teller resonance is seen most clearly in charge-exchange reactions at a small momentum transfer, $q \sim 0$.

It can be seen from (3) that there are two mechanisms which might cause the Gamow-Teller resonance to approach the analog resonance with increasing $N-Z$ either (a) a term which is linear in $N-Z$ in the case $g'_0 < f'_0$ or (b) spin-orbit corrections which are proportional to $(N-Z)^{-1}$ in the case $g'_0 \approx f'_0$ (or a combination of these factors).

Experimental data on the differences $E_{\mathrm{GTR}} - E_{\mathrm{AR}}$ were recently put in systematic form by Horen *et al.*[7] In approximating the data with a linear dependence on $(N-Z)/A$,

$$E_{\mathrm{GTR}} - E_{\mathrm{AR}} = -30{,}0\,(N-Z)/A + 6{,}7 \text{ (MeV)}, \tag{5}$$

Horen *et al.* used assumption (a) as an *a priori* assumption. Clearly, this approximation leads to values of the difference $f'_0 - g'_0$ which are much too high, and it essentially ignores the suppression of the spin-orbit interaction.

To determine the difference between the constants f'_0 and g'_0, we carried out numerical calculations of E_{GTR} from the theory of finite Fermi systems with a one-particle Woods-Saxon potential and with self-consistency through the constant f'_0

TABLE I. *Energies (MeV) of the Gamow–Teller resonance calculated from the theory of finite Fermi systems by various methods*

Final nucleus	Semiclassical model		Self-consistency through the constant f'_0		Experimental	
	E_{GTR}	g'_0/f'_0	E_{GTR}	g'_0/f'_0	E_{GTR}	E_{AR}
^{90}Nb	10.3	0.926	8.2	0.938	8.7	5.1
^{92}Nb	13.5	0.926	–	–	12.4	9.3
^{94}Nb	13.4	0.926	–	–	12.3	10.1
^{112}Sb	10.4	0.926	10.1	0.938	10.0	7.1
^{120}Sb	11.9	0.926	12.1	0.938	12.3	10.2
^{124}Sb	13.7	0.926	14.3	0.938	13.1	12.1
^{208}Bi	15.7	0.926	15.3	0.938	15.6	15.2

(the procedure used for these calculations is described in Ref. 6, for example), In addition, we carried out calculations from a semiclassical model of which (3) is a particular approximation.

The results of these calculations show that, in contrast with approximation (5), the same experimental data can be explained well under assumption (b). The ratio of constants, universal for all the nuclei, is approximately

$$g'_0/f'_0 = 0.93 \div 0.94 \qquad (6)$$

i.e., it approaches the ratio of the Wigner scheme, (2). The primary reason that the Gamow-Teller resonance and the analog resonance move closer together in the effective suppression of the spin-orbit interaction.

In summary, these calculations confirm the hypothesis of a reconstruction of broken SU(4) symmetry, both in the sense that the constants f'_0 and g'_0 are approximately equal and in the sense of the mechanism for the degeneracy of the Gamow-Teller resonance and the analog resonance. Measurements of the Gamow-Teller resonance and the analog resonance in ^{238}U would constitute a critical experimental test of the approximate equality of the constants.

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