Description of Gamow-Teller resonances in deformed nuclei

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The strength functions for the (p,n) and (n,p) transitions in ^{162}Dy, ^{166,168}Er, and ^{238}U are calculated in the random-phase approximation. The Gamow-Teller resonance peak is at 17–18 MeV and accounts for about 50% of the strength of this resonance. About 30% of the strength is at low energies.

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Gamow-Teller resonances and charge-exchange resonances of the electric type have recently been observed experimentally in many nuclei.[1,2] Their characteristics have been calculated for several magic nuclei. The charge-exchange resonances can be described by the quasiparticle-phonon nuclear model,[3,4] by the same approach as in Ref. 5, where neutron-proton phonons were introduced to calculate $T_>$ for the giant dipole resonance in spherical nuclei. In the present letter we use the random-phase approximation to derive equations for describing the Gamow-Teller resonances, and we calculate the strength functions for the (p,n) and (n,p) reactions for several deformed nuclei.

The Hamiltonian of the quasiparticle-phonon model consists of the average nuclear field, in the form of a Woods-Saxon potential; the pairing interaction; and multipole-multipole and spin-multipole–spin-multipole interactions. We adopt the following description of the spin-multipole–spin-multipole interaction:

$$\kappa_1^{(1)} (t_1^+ t_2^- + t_1^- t_2^+) \vec{\sigma}_1 \vec{\sigma}_2 , \tag{1}$$

where $\kappa_1^{(1)}$ is the constant of the isovector interaction, and $t^{\pm} = t_x \pm it_y$. We transform the Hamiltonian of the model to the form used in Ref. 5.

We perform a Bogolyubov transformation and introduce the *np*-phonon operators

$$\Omega_{\rho\mu i} = \frac{1}{\sqrt{2}} \sum_{rs} \{ \psi_{rs}^{\mu i} A(rs, \mu\rho) - \varphi_{rs}^{\mu i} A^+(rs, \mu - \rho) +$$

$$+ \bar{\psi}_{rs}^{\mu i} \bar{A}(rs, \mu\rho) - \bar{\varphi}_{rs}^{\mu i} \bar{A}^+(rs, \mu - \rho)\} , \tag{2}$$

where

$$A(rs, \mu\rho) = \sum_{\rho'} \delta_{\rho'(K_r - K_s), \rho\mu} \alpha_{s - \rho'} \alpha_{r\rho'} ,$$

$$\bar{A}(rs, \mu\rho) = \sum_{\rho'} \delta_{\rho'(K_r + K_s), \rho\mu} \alpha_{r\rho'} \alpha_{s - \rho'} ,$$

$\alpha_{r\rho}$ is the quasiparticle absorption operator, r and s are the quantum numbers of the proton and neutron single-particle states, and $\rho = \pm 1$.

In the random-phase approximation, the equations for the energy $\Omega_{\mu i}$ of the *np* single-phonon states are

$$F(\Omega_{\mu i}) = (1 - \kappa_1^{(1)} X_1^{\mu i})(1 - \kappa_1^{(1)} X_2^{\mu i}) - (\kappa_1^{(1)} X_{12}^{\mu i})^2 = 0, \tag{3}$$

where

$$X_1^{\mu i} = \sum_{rs} 4\{(f_{rs}^{\mu})^2 + (\bar{f}_{rs}^{\mu})^2\} \left\{ \frac{u_r^2 v_s^2}{\epsilon(rs) - \Omega_{\mu i}} + \frac{v_r^2 u_s^2}{\epsilon(rs) + \Omega_{\mu i}} \right\}, \tag{4}$$

$$X_2^{\mu i} = \sum_{rs} 4\{(f_{rs}^{\mu})^2 + (\bar{f}_{rs}^{\mu})^2\} \left\{ \frac{v_r^2 u_s^2}{\epsilon(rs) - \Omega_{\mu i}} + \frac{u_r^2 v_s^2}{\epsilon(rs) + \Omega_{\mu i}} \right\} , \tag{4'}$$

$$X_{12}^{\mu i} = \sum_{rs} 4 \left\{ (f_{rs}^{\mu})^2 + (\bar{f}_{rs}^{\mu})^2 \right\} \left\{ \frac{1}{\epsilon(rs) - \Omega_{\mu i}} + \frac{1}{\epsilon(rs) + \Omega_{\mu i}} \right\} u_r v_s v_r u_s , \tag{5}$$

$\epsilon(rs) = \epsilon(r) + \epsilon(s)$, $\epsilon(r)$ is the quasiparticle energy, u_r and v_r are the coefficients of the Bogolyubov transformation, and the matrix elements are $f_{rs}^{\mu} = \langle r\rho | \sigma_\mu t^- | s\rho \rangle$, $\bar{f}_{rs}^{\mu} = \langle r\rho | \sigma_\mu t^- | s - \rho \rangle$.

Using the strength-function method,[3,4] we find the strength functions for the (n,p) and (p,n) transitions in the form

$$B(np) = \frac{1}{\pi} \mathrm{Im} \left\{ \frac{1 - \kappa_1^{(1)} X_1(z)}{2\kappa_1^{(1)} F(z)} \bigg|_{z = \Omega + i\Delta/2} \right\}, \tag{6}$$

$$B(pn) = \frac{1}{\pi} \operatorname{Im} \left\{ \frac{1 - \kappa_1^{(1)} X_2(z)}{2\kappa_1^{(1)} F(z)} \Bigg|_{z = \Omega + i\Delta/2} \right\} , \tag{7}$$

where Δ is a smearing parameter.

Calculations have been carried out for ^{162}Dy, ^{166,168}Er, and ^{238}U with the maximum possible number of single-particle levels. We used the same parameters for the Woods-Saxon potential and the pairing constants as in Ref. 4, $\kappa_1^{(1)} = 17/A$ MeV, smaller than the values given in Refs. 1, 2, and 6 because the incorporation of many single-particle states.

Figure 1 shows some representative results of the calculations, for ^{166}Er. Specifically, this figure shows the strength functions for the (n,p) and (p,n) transitions accompanied by the excitation of a Gamow-Teller resonance; these strength functions were calculated with the value $\Delta = 0.5$ MeV. The strength of the resonance is distributed over the interval 5–40 MeV and has a strong peak at 17.4 MeV (with respect to the ground state of the target nucleus). This peak lies 0.7 MeV above the isobar analog state[7] and is approximately equal to the experimental value. For ^{168}Er and ^{162}Dy, the peak lies 1.7 and 1.1 MeV, respectively, above the isobar analog state. In the distribu-

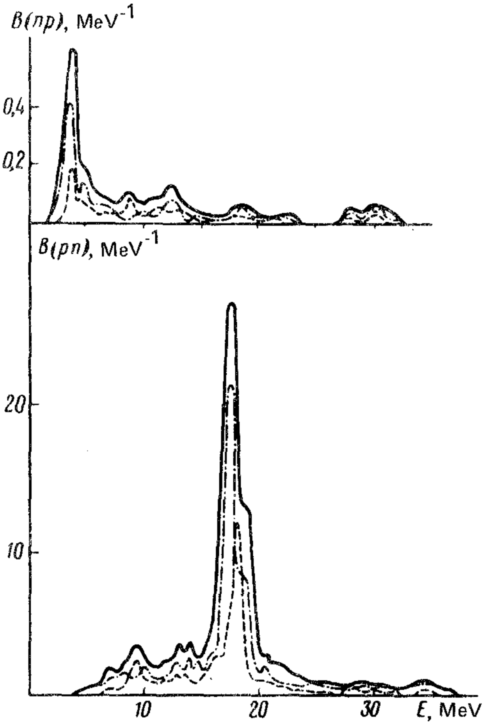

FIG. 1. Strength functions for the (n,p) and (p,n) reactions in ^{166}Er. Dashed curves—Strength function with $I^{\pi}K = 1^{+}0$; dot-dashed curves—with $I^{\pi}K = 1^{+}1$; solid curves—their sum.

tion of the resonance strength we can distinguish a low-energy part (5–16 MeV), the peak (16–19 MeV), and a high-energy part (19–40 MeV), which contain respectively 31%, 51%, and 18% of the strength. The same strength distribution is found for all the nuclei considered in these calculations. The energy centroid of the low-energy part is 11.7 MeV, 5.7 MeV below the resonance peak. According to the calculations, about 1% of the strength in ^{168}Er and ^{238}U is at an energy of about 50 MeV. In the deformed nuclei, the Gamow-Teller resonance consists of components with $I^{\pi}K$ values of $1^{+}0$ and $1^{+}1$, which are split by 0.6 MeV in the case of ^{166}Er and 0.3 MeV in the case of ^{238}U. The Gamow-Teller peak is slightly broader than that for spherical nuclei, and more of the strength is at low energies. The strength of the (n,p) transitions is distributed over the range 2–30 MeV, with an energy centroid of 12 MeV for the nuclei from the rare-earth region and 15 MeV for ^{238}U. For the rare-earth nuclei the ratio $B(pn)/B(np)$ is 20, while that for ^{238}U is 57. For the Gamow-Teller resonance there is the simple sum rule[8]

$$B(pn) - B(np) = 3(N - Z).$$

Our calculation for all the nuclei yield values of 98–99% of $3(N - Z)$, in very close agreement with this rule.

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