Microscopic model for calculating *2p2h* configurations in magic nuclei

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A model is formulated which makes it possible to take into consideration the influence of $2p2h$ configurations in nuclei to within second order in the interaction of nucleons with phonons.

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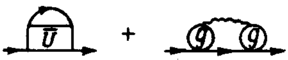
One of the most important problems in the microscopic theory of the nucleus is that of calculating two-particle-two-hole ($2p2h$) configurations. This problem has acquired considerable urgency in connection with the discovery of the new multipole giant resonances (MGR's)—see the recent reviews.[1] In particular, up to now for intermediate and heavy nuclei there have been no microscopic calculations of the most important integral characteristic of MGR's—the width. Such calculations would consider successively both the one-particle continuum and the $2p2h$ configurations. This latter problem gives rise to considerable difficulties in the theory of MGR's and also in the theory of some other nuclear levels.

Numerous attempts have been made to calculate the $2p2h$ configurations (see Ref. 1). The primary procedure, employed in microscopic approaches for intermediate and heavy nuclei, is to use $1p1h$ phonons, describable within the framework of the conventional random phase method. The problem is that of successively calculating the effects associated with the phonons. The fact that in the problem using the phonons there is a small parameter $g^s_{12}/(\epsilon_{12}-\omega_s)\approx \beta_s A^{1/3}$ (we estimate the denominator as $\epsilon_F A^{-1/3}$), where g is the amplitude of the interaction of quasiparticles with phonons, β_s is the dynamic deformation parameter for the sth phonon with energy ω_s, ϵ_{12} is the difference of the one-particle energies, is important here. In the Pb^{208} nucleus $\beta_s \lesssim 0.05$; therefore it can be hoped that a restriction to terms of order g^2 will be valid at least for magic nuclei.

We will formulate a simple microscopic model for calculating the $2p2h$ configurations in nuclei without pairing and without particle-particle interaction, which utilizes $1p1h$ phonons and is restricted to a consideration of effects of order g^2. The starting assumption of the model is the choice of the mass operator for the one-particle Green's function G in the form

$\Sigma =$  $= \Sigma_1 + M(\epsilon)$ (1)

where the amplitude g satisfies the well-known equation $g = UGGg$,[2] which corresponds to the random phase equation in the Green's function method. $\bar{U}$ is the amplitude of some effective $1p1h$ interaction, generally different from U (U is assumed to be known).

The expression for the Green's function G, corresponding to the mass operator (1), has the form

$$G = G_1 + G_1 M G_1 , \qquad (2)$$

with an accuracy to g^2, where G_1 satisfies the Dyson equation with mass operator Σ_1: $G_1 = G_0 + G_0(\Sigma - M)G_1$. We write G_1 near a pole in the form

$$[G_1]_{\lambda\lambda'} = G_{1\lambda}\delta_{\lambda\lambda'} = \delta_{\lambda\lambda'}\, a_{1\lambda}[\epsilon - \epsilon_{1\lambda} + i\delta \,\mathrm{sign}\, \epsilon_{1\lambda}]^{-1} \qquad (3)$$

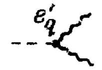
and we will express $a_{1\lambda}$ and $\epsilon_{1\lambda}$ in terms of the known "old" phenomenological residues a_λ and energies ϵ_λ, entering into the "old" polar part of the G-function. In addition, it is necessary to express the quantities in the Schrödinger equation for the "new" one-particle functions $\phi_{1\lambda}$, which now diagonalize G_1, in terms of the "old" quantities; the effective mass m/m^* and the one-particle potential $\mathcal{U}(\mathbf{r})$. Using the appropriate definitions in (2), it is not hard to obtain:

$$\epsilon_{1\lambda} = \epsilon_\lambda - a_{1\lambda} M_{\lambda\lambda}(\epsilon_\lambda) , \qquad (a_1)^{-1} = a^{-1} + \partial M / \partial \epsilon_\lambda ,$$

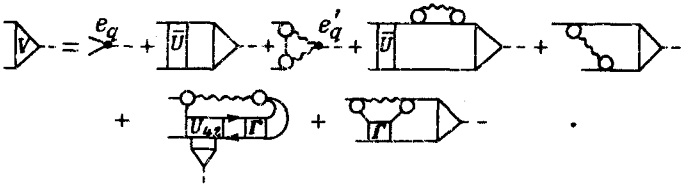
$$\left(\frac{m}{m^*}\right)_1 = \frac{a_1}{a}\left(\frac{m}{m^*}\right) - a_1 2m \frac{\partial M}{\partial p^2} , \qquad \mathcal{U}_1 = \frac{a_1}{a}\mathcal{U} - a_1 M_F . \qquad (4)$$

If Σ_1 in (1) does not depend on ϵ (for example, if Σ_1 us the Hartree-Fock part of Σ), then $a_1 = 1$.

The equation for the effective field V, arising in a nucleus due to the action of the external field V^0, is obtained by the variation of Eq. (1) in the external field[2]: $V = V^0 + \delta\Sigma$ (in the variation of Σ_1 it must be assumed that $\bar{U} = 0$). The G-function (2) must be substituted into the resulting equation for V, and it is everywhere restricted to terms with g^2. For the change of the D-function in the field in this case it is only necessary to retain the term with the effective phonon charge e_q', not containing g:

$\delta D =$  $= D V_1^0 D$. (5)

As a result we obtain an equation for V which can be written graphically as (only the most typical diagrams have been retained)



(6)

Here the Green's function G_1 is associated with the lines; the total amplitude Γ satisfies the equation $\Gamma = U + UGG\Gamma$.[2]

The first two terms on the right side of (6) correspond to the usual random phase method, but with another interaction $\bar{U}$ and with corrections to ϵ_λ, ϕ_λ, a_λ. The rest of the diagrams correspond to the calculation of the $2p2h$ configurations, which in our case are "convoluted" into the configuration "$1p1h$ + phonon."

The polarization operator, determining the probabilities of the transitions within an accuracy of g^2, has the form

(7)

It is seen that a consideration of the $2p2h$ configurations gives additional corrections here, described by the last two diagrams.

Let us point out some general features of the proposed model.

1. If (6) and (7) are written in a coordinate representation, which makes it possible to take account of the one-particle continuum correctly (see Ref. 1), then we obtain the regular method of calculating the properties of MGR's with both the continuous spectrum as well as the $2p2h$ configurations taken into account (the approximation "$1p1h$ + $2p2h$ + continuum"). The model considered for taking account of the $2p2h$ configurations contains as special cases all of the best known microscopic approaches to MGR theory for intermediate and heavy nuclei, which consider the $2p2h$ configurations and use the $1p1h$ phonons (see the reviews[1] and the new paper[3]).

2. The model we have outlined makes it possible to take account of several unstudied effects in the microscopic theory of MGR's, for example, the role of δg—the change in the amplitude of g in the external field [last two diagrams in (6)], the effect of the diagrams with the effective phonon charge e_q'. For $M1$ transitions e_q' is known (and large!): $e_q' \approx Z/A$. With the resonant nature of the factors in the diagrams with e_q' taken into account the latter can be important for explaining the experimental "disappearance" of the $M1$ resonance in magic nuclei.[4] Preliminary estimates[1)] for the probabilities of the $M1$ resonance in ^{208}Pb have shown that the contribution of the last two diagrams in (7) is quite large. This means that it is apparently necessary to take account of the $2p2h$ configurations to explain the "disappearance" of the $M1$ resonance.

3. The phenomenological one-particle characteristics [ϵ_λ, $a_\lambda \approx 1$, $(m/m^*) \approx 1$], which are usually used in microscopic calculations, already contain the coupling effects with phonons. In our results (6) and (7) the function G_1 enters in which these effects are excluded. The formulas (4) make it possible to isolate these effects; in this case all four corrections must generally be taken into consideration. These corrections can prove to be important in a number of specific cases in both odd and even-even nuclei.

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[1)]Performed jointly with V.N. Tkachev.

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