

1.

On microscopic theory of pygmy- and giant resonances: accounting for complex $1p1h \times$ phonon configurations

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2.

Motivation: to build a **consistent** and predictive approach to describe properties of pygmy- and giant resonances accounting for RPA and complex 1p1h \times phonon configurations

Method: with the use the RPA phonons, to generalize the standard self-consistent Theory of Finite Fermi –systems (TFFS) to consistently take into account the phonon coupling (PC) for the main TFFS quantity – **the vertex V**, which defines the nuclear polarizability

Why is this necessary?

1. **New experimental possibilities** in the energy region of pygmy-dipole and giant multipole resonances (PDR & GMR)
2. **New modes in this energy region** like irrotational and vortical kind of motion, the upbend phenomenon at 1-3 MeV
3. **Absence of the reasonable explanation of the PDR fine structure** even in ^{208}Pb . Moreover, almost the same, in fact, is also for the explanation of the **known M1 resonance in ^{208}Pb** (see the talk by V.I. Tselyev on Monday)
4. **Physically, the problem is clear - inclusion of PC – but only in principle.** The earlier explanations to include PC in addition to RPA were very numerous see, for example, review [Kamerdzhev et al., Phys. At. Nucl. 82,366(2019)], however, they still have room for the improvement

3. Standard self-consistent TFFS (magic nuclei) :

The vertex V , which defines the nuclear polarizability, satisfies the equation:

$$V = V_0 + FAV \quad (1)$$

Here F is the effective interaction, which in the selfconsistent TFFS is calculated as the second variational derivative of the energy density functional and the mean field calculated as the first variational derivative of the energy density functional.

ph- propagator: $A = \int G(\epsilon) G(\epsilon + \omega) d\epsilon \quad (2)$

The phonon creation amplitude g satisfies the equation:

$$g = FAg. \quad (3)$$

These equations correspond to RPA approach written in the Green function language. **This is our initial position**, with the use the RPA phonons (3), first of all,

Main references:

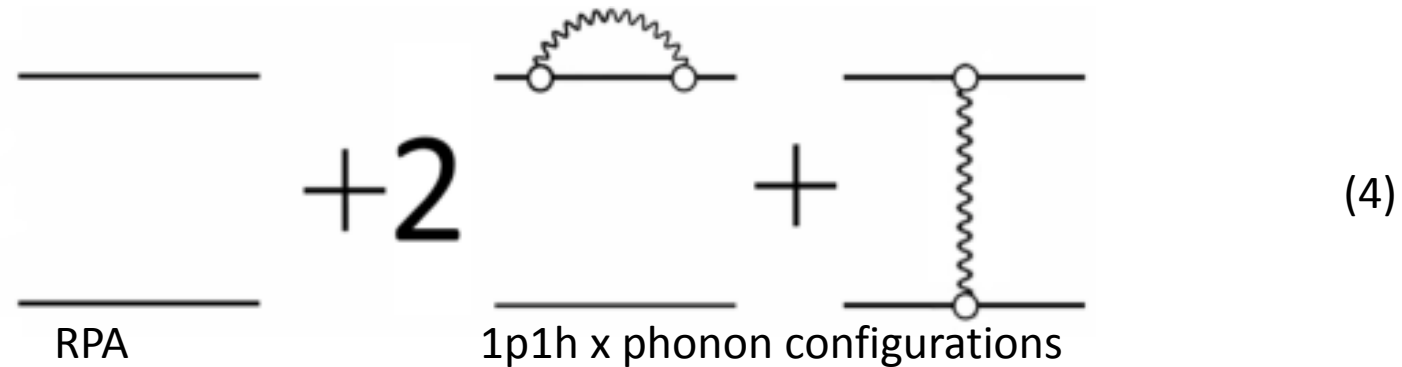
[1].A.B. Migdal, *Theory of finite Fermi Systems and Application to Atomic Nuclei* (Nauka, 1965)

[2].V.A. Khodel, E.E. Saperstein, Phys.Rep.92, 183 (1982)

4.

Some earlier results with Phonon Coupling (PC)
in the pygmy – and giant resonances (PDR & GMR) field

Diagrams corresponding to the simplest
 ph-propagator with PC :



In the Green Function language, this generalization has been considered in [1] and [2]:

[3] S.P. Kamerdzhev, Yad. Fiz. 38, 316 (1983) [Sov. J. Nucl. 38,188 (1983)]

[4] V. I. Tselyaev, Yad. Fiz. 50, 1252 (1989) [Sov. J. Nucl. Phys. 50, 780 (1989)]

In [4], the problem of second order poles in [3] has been solved by the developing of the (in modern language) Time Blocking Approximation (TBA) .

Later, the approach was considerably improved and christened by the name of **TBA approach** for magic nuclei, or QTBA for nuclei with pairing. **Its physical sense** is a partial generalization of the propagators (2) and (4) of the equation for the vertex V

5. **Our goal** is to consistently account for PC in the equation for the TFFS vertex V :
- 1) within the g^2 approximation
 - 2) with the aim to consider **only** 1p1h and complex 1p1h+phon configurations :

g^2 corrections to the vertex V:

$$\Delta V = 2 \left[\text{Diagram 1} + \text{Diagram 2} \right]$$

$$\Delta V = 2gGD\delta V + \delta^{(2)}V D,$$

where G and D are the Green functions for quasiparticle and phonon, δV and $\delta^{(2)}V$ are the first and second variation of V in the phonon field

6.

δV and $\delta^{(2)}V$ satisfy the integral equations with two and five free terms:

$$\delta V = \delta F A V + F \delta A V + \underline{F A \delta V}$$

$$\delta^{(2)}V = \delta^{(1)}\delta^{(1)}V = \mathbf{F \delta^{(2)}AV} + \delta F \delta A V + \dots + \underline{F A \delta^{(2)}V}$$

In the present approximation we will take only free terms into account (without underlined integral parts)

Let's, for example, consider:

$$\delta^{(2)}A = \delta \tilde{1} \delta \tilde{1} G_1 G_2 = 2 \text{ [Diagram 1]} + 2 \text{ [Diagram 2]} + \text{ [Diagram 3]}$$

Here, the second graph gives the so-called **tadpole term [2]** in the new equation for the vertex \tilde{V}

See the next slide №7, where the rectangle means the effective interaction F of Landau-Migdal

Our approximation means that we account only for complex 1p1h phonon configurations

7.

$$\tilde{V} = e_q V^0 + \text{F} \tilde{V} + 2 \text{F} \tilde{V} + \text{F} \tilde{V} + 1$$

$$2 \text{F} \text{V}^{\text{tad}} \tilde{V} + 2 \text{F} \tilde{V} + 2 \text{F} \tilde{V}$$

$$2 \text{F} \tilde{V} + 2 \text{F} \tilde{V}$$

$$2 \delta F \tilde{V} + 2 \delta F \tilde{V}$$

$$2 \delta F \text{F} \tilde{V} + 2 \text{F} \delta F \tilde{V}$$

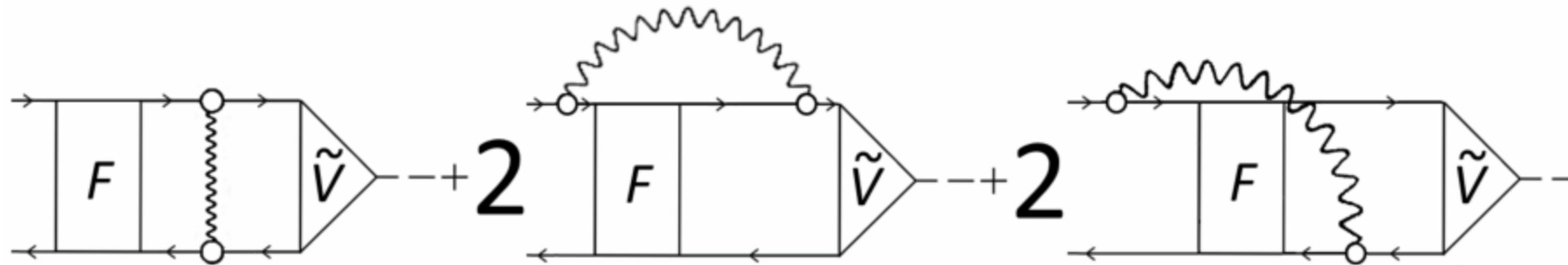
$$2 \delta F \delta F \tilde{V} + \text{F} \tilde{V}$$

Results:

Discussion of the new equation for vertex \tilde{v}

8. One can easily see that all obtained terms contain 1p1h, i.e. RPA, and only complex 1p1h \times phonon configurations (without two-phonon ones)
The most interesting terms are in line 1 and 2, because one can think (?) that the contributions of the terms in lines 3-6 are small
1. The terms in line 1 correspond to the TBA model, of course, under condition that the TBA summation should be performed. This is despite the fact that the derivation method of TBA was different and was based on the Bethe-Salpeter equation
 2. The terms in line 2 are new for the considered energy region. Moreover, the first term in line 2, which gives the **dynamic tadpole effect**, is quite new for PDR&GMR (and unknown !)
 3. Within the considered method, one can (should !) take into account all the numerous new (as compared to RPA ones) ground state correlations, including three-quasiparticle GSCs
 4. Numerous calculations are very necessary !

9. Terms in the line 1 and line 2 with the **phonon induced interaction** :
the old one (line 1) and four new ones (line 2)



10. Phonon-exchange nuclear interactions in the theory of nuclear polarizability

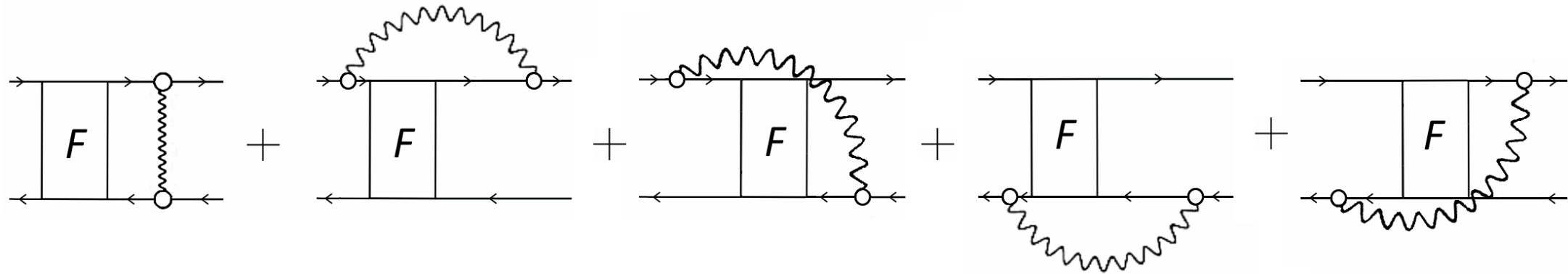


Fig.1 Phonon-exchange interactions between nucleons. The rectangle means the effective interaction F of Landau-Migdal. Straight and wavy lines correspond to single-particle and phonon Green functions, circles with a wavy line stand for the amplitude of phonon production g .

These graphs contain g^2 corrections

Our very preliminary estimations showed that all these graphs are comparable

Probably, they should be of interest in the physics of electron systems....

Conclusion

11.

1. We have extended the self-consistent TFFS to the new energy region of PDR and GMR in order to describe **on an equal footing** both the ground state and the whole region of nuclear excitations up to GMR energies (30-35 MeV). **In fact , this is a beginning of the third stage of developing TFFS**
2. Accounting for our new effects is of highest interest, first of all, for calculation of fine structures of PDRs and other pygmy resonances, which are in the energy region of the neutron energy binding. Therefore, the results should be useful in the nuclear data business

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12.

Many thanks !