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LOW–LYING 1^- STATE AND FAST E1 TRANSITIONS IN ^{144}Sm

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The nuclear field theory approach to the treatment of two–phonon excitations in the nuclear spectrum is applied to the low lying 1^- state in nucleus ^{144}Sm. Theory provides a quantitative account of the experimental findings.

Low–lying 1^- states in nuclei in the region of N=82 show fast E1 transitions (B(E1)$\approx 10^{-3}$ W.u.), much faster than the majority of E1 transitions in the same mass region [1]. The energies of these states are approximatively equal to the sum of the energies of the lowest 2^+ and 3^- states, suggesting an interpretation in terms of two–phonon states $(2^+ \otimes 3^-)$.
In the present short note we analyze in detail recent data in the nucleus ^{144}Sm [2], [6] within the framework of nuclear field theory. [3]

A systematic method to analyze the various facets of collective states in nuclei is provided by the Nuclear Field Theory (NFT) [3]. In it the free fields, corresponding to vibrational (boson) and quasi–particle (fermion) degrees of freedom and containing a large fraction of the many–body nuclear correlations, interact through both the model bare interaction and the particle–vibration coupling vertices. Unlike other systems with many degrees of freedom, the nuclear bosonic fields are built out of the quasi–particle degrees of freedom. So it is a characteristic of the basis to be overcomplete and to contain states violating the Pauli principle. It has been shown that the NFT correctly treats these effects to all orders of perturbation theory.

The NFT allows to construct diagrammatically the interaction among phonons. Because of the rapid convergence of the NFT perturbative expansion, only the lowest order diagrams are in general important [4].

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The nucleus ^{144}Sm is a semi-magic nucleus with 82 neutrons and 62 protons. To determine the single-particle properties, we use a standard Woods–Saxon potential. For the protons, a static deformation of the pairing field is established and for the calculation we use the quasiparticle representation in the nuclear BCS approximation [5]. The residual particle–hole interaction is of multipole–multipole type, and the coupling costants are determined from the experimental data for the energies and the electromagnetic transition B(Eλ) values for the lowest states of a given multipolarity in the Random Phase Approximation. The particle–vibration coupling vertices are, in this way, fully determined [3].

The NFT allows to construct diagrammatically the effective electromagnetic matrix elements corresponding to the transitions between the basic states. The external field is modified by the mediation of the collective states, in particular the Giant Dipole Resonance (GDR) for the E1 transition is shown in Fig.1.

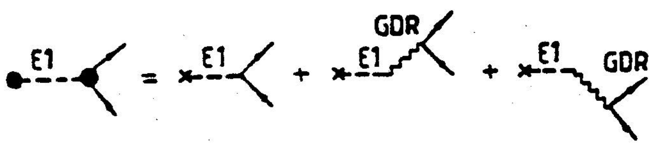

Fig. 1. Renormalization of single-particle moment E1 from particle–vibration coupling.

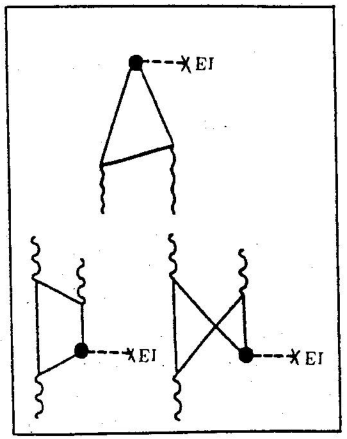

Fig. 2. Diagrams representing the basic topologies which are used in the calculation of transition matrix elements. The arrows corresponding to the fermion states have been omitted from the figure so the drawing should represent all the possible combinations of particle and hole lines.

These graphs lead to a simple renormalization of the coupling, given by

$$e_{eff} = e(1 + \chi(\Delta E)) \quad ,$$

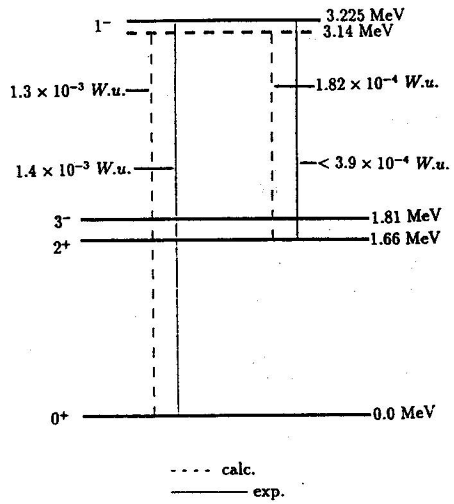

Fig. 3. Partial level scheme containing proposed 1$^-$ state for ^{144}Sm. Measured and calculated E1 transition rate are in Weisskopf units

where the polarizability can be written as [5]

$$\chi(\Delta E) \approx -0.76 \frac{(\hbar\omega_D)^2}{(\hbar\omega_D)^2 - (\Delta E)^2} \quad .$$

The quantity $\Delta E = E - \hbar\omega_{3^-}$ is the energy of the dipole transitions, very small in our cases as compared to the GDR energy $\hbar\omega_D \approx 15MeV$. Consequently one can use the static value of the polarizability

$$\chi(\Delta E = 0) \approx -0.76 \quad .$$

Adding the corrections for the center of mass motion, we obtain

$$e_{eff}(E1) = -\frac{1}{2}e\left(\tau_z - \frac{N-Z}{A}\right)(1+\chi) \quad .$$

In the case of ^{144}Sm one find $e_{eff}(E1) \approx 0.17e$ for protons and $e_{eff}(E1) \approx -0.13e$ for neutrons.
The NFT diagrams used in the calculation of the transition matrix elements are shown in Fig. 2.

The B(Eλ) calculated values are the result of a strong cancellation among the contributions displayed above. In the case of the 1$^-$ state, the experimental data are accounted for not only in the case of the transition from the two–phonon $(2^+ \otimes 3^-)_{1^-}$-state to the ground–state but also (this transition is not allowed in the harmonic model) to the first 2$^+$ state (cf. Fig. 3).

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