Dipole excitations in ^{162}Er-^{166}Yb

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Introduction

Recently, it has been shown that nuclei having particle-hole symmetry reveal similar excitation patterns up to 10^+ in yrast bands (Saygı, 2018a; Saygı,2018b; Saygı 2019). In this nuclei, almost overlay of the γ -ray transitions from equal spin and parity states ($E(2^+)$, $E4^+/E2^+$) and their related reduced transition probabilities (B(E2)) with equal $N_\pi N_\nu$ number are remarkable.

The N_pN_n (=$4N_\pi N_\nu$) quantity is an indicator of the symmetry and depends on valence nucleon (or holes) number from the nearest closed shell by considering the subshell closures, which simplifies the systematics of excitation energies and related B(E2; $L^+ \rightarrow (L-2)^+$) values of excited states in nuclei placed in the different mass regions of nuclear chart (Casten, 1985; Casten & Zamfir, 1999). The Pseudo-Mirror Nuclei (PMN) concept is based on the $N_\pi N_\nu$ quantity (Moscrop et al., 1988). In the scheme of pseudo-mirror nuclei, if two nuclei possess the same $N_\pi N_\nu$ quantity, then they are expected to exhibit the same E_4^+ / E_2^+ therefore similar nuclear structures.

Motivations of the present work are to figure out what the range of symmetrical behaviour PMN couple does extend and how reduced transtition probabilities of high-energy transitions do behave in PMN couple? In order to answer these two questions, we are aiming to investigate the dipole excitation (2-20 MeV) modes in ^{162}Er and ^{166}Yb. These features have not been investigated within this perspective so far.

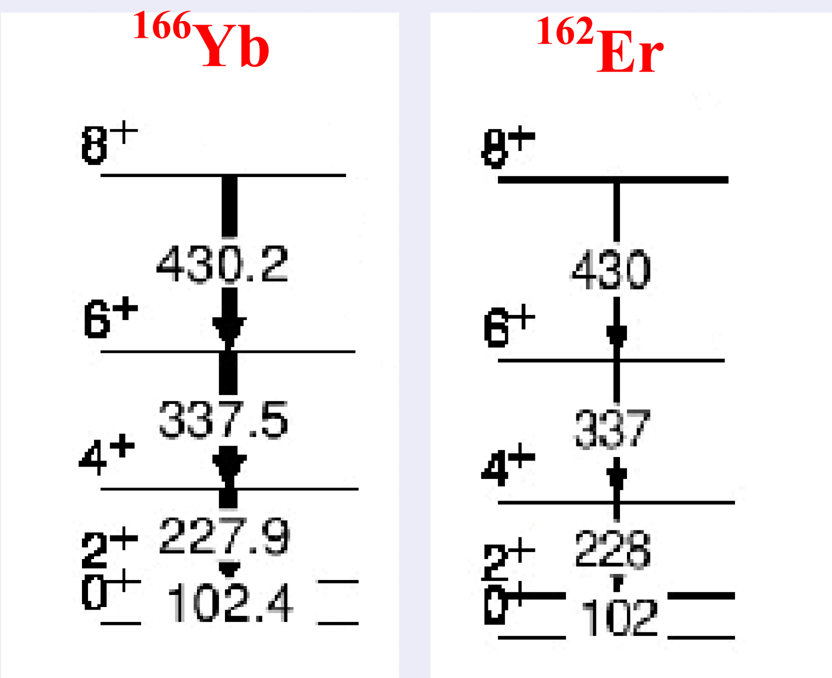
The electric dipole responses of the ^{162}Er and ^{166}Yb PMN couple were studied using quasiparticle, random-phase approximation (QRPA) in 2-20 MeV energy interval. The excitation energies, transition probabilities, splitting behaviors of E1`s into K=0 and K=1, and photoabsorbtion cross-section were investigated. The nuclear model we adopted for our calculation was phenomenological QRPA, which takes into account the pairing effect and where the effective separable interactions are chosen as restoring the broken translational and Galilean symmetries. Microscopic models based on the QRPA are well known for their accuracy at describing collective modes, such as giant resonances (Giai, 1983), so the main limit of our model is it not being fully self-consistent. The QRPA model employed here has already succeeded at describing low-lying collective states in well-deformed (Repko, 2017; Tabar et al., 2020; Demirci Saygı et al., 2020), transitional, and γ-soft nuclei Guliyev et al., 2002; Linneman et al., 2003).

^{162}Er-^{166}Yb Nuclei

1. Same N_pN_n Number

	Z	N	N_p	N_n	N_pN_n
^{162}Er	68	94	over 66 mid shell. So, Closer to 82. the situation with respect to 82: 14 less than 82. In this case, **14 protons hole**	under the 104 middle shell. so it's closer to the 82 closed shell. the situation with respect to 82: 12neutrons more . In this case: **12 neutron particles**	168
^{166}Yb	70	96	over 66. Closer to 82. the situation with respect to 82: 12 less than 82. In this case, **12 protons hole**	under the 104 middle shell. so it's closer to the 82 closed shell. the situation with respect to 82: 14 neutrons more . In this case: **14 neutron particles**	168

2. Overlaying Level schemes



163Yb 11.05 M ε: 100.00%	164Yb 75.8 M ε: 100.00%	165Yb 9.9 M ε: 100.00%	166Yb 56.7 H ε: 100.00%	167Yb 17.5 M ε: 100.00%
162Tm 21.70 M ε: 100.00%	163Tm 1.810 H ε: 100.00%	164Tm 2.0 M ε: 100.00%	165Tm 30.06 H ε: 100.00%	166Tm 7.70 H ε: 100.00%
161Er 3.21 H ε: 100.00%	162Er STABLE 0.139%	163Er 75.0 M ε: 100.00%	164Er STABLE 1.601%	165Er 10.36 H ε: 100.00%
160Ho 25.6 M ε: 100.00%	161Ho 2.48 H ε: 100.00%	162Ho 15.0 M ε: 100.00%	163Ho 4570 Y ε: 100.00%	164Ho 29 M ε: 60.00% β-: 40.00%

Theory

TGI-QRPA

The TGI-QRPA model Hamiltonian (Eq(1)) includes H_{sqp} single particle Hamiltonian, W_{dip} isovector part of the dipole-dipole (λ = 1) interaction , h_0 and h_Δ separable effective interactions which restoring the broken Translational and Galilean symmetry of single particle Hamiltonian (Pyatov, Salamov, 1977) and these statements are given in following equations

$$H = H_{sqp} + h_0 + h_\Delta + W_{dip}$$

$$H_{sqp} = \sum_{qq'} \varepsilon_s(\tau) B_{qq'}(\tau) \qquad h_\Delta = -\frac{1}{2\beta} \sum_\mu [U_\Delta, R_\mu]^+ [U_\Delta, R_\mu]$$

$$W_{dip} = \frac{3}{2\pi} \chi_1 \left(\frac{NZ}{A}\right)^2 \left(\vec{R}_n - \vec{R}_p\right)^2 \qquad h_0 = -\frac{1}{2\gamma} \sum_\mu [H_{sqp}, P_\mu]^+ [H_{sqp}, P_\mu]$$

Here, $\varepsilon_s(\tau) = \sqrt{\Delta_\tau^2 + (E_s(\tau) - \lambda_\tau)^2}$ is the quasiparticle energy of a nucleon where is the BCS paring energy gap, plays the role of the chemical potential which physically is the Fermi level energy. The wave function with a single phonon defined for electrical dipole excitation is determined.

$$|\Psi_i\rangle = Q_i^+ |\Psi_0\rangle = \sum_{ss',\tau} [\psi_{ss'}^i(\tau) A_{ss'}^+(\tau) - \varphi_{ss'}^i(\tau) A_{ss'}(\tau)] |\Psi_0\rangle$$

The motion equation solution technique used to solve the TGI-QRPA Hamiltonian is used in the second quantization method. ω_i excitation energies and photoabsorbtion cross section are obtained and the details of this approach can be found in (Kuliev et al., 2010;Demirci Saygı et. al, 2020).

Electric Dipole Excitations

Two characteristic excitation based on spin and parity of dipole transition:

1^- = electric dipole (E1)

1^+ = magnetic dipole (M1)

Electric dipole: Center of mass for neutrons and protons oscillates against each other (macroscopically). The electric dipole (E1) modes of the nuclei are determined by the giant dipole resonance, a high-stimulated collective mode above the particle emission threshold (Berman and Fultz, 1975). Electric dipole excitations (according to energy ranges): Low-lying (2-4 MeV), Pygme Dipole Resonce PDR (5-8 MeV), Giant Dipole Resoance GDR 8-20 MeV),

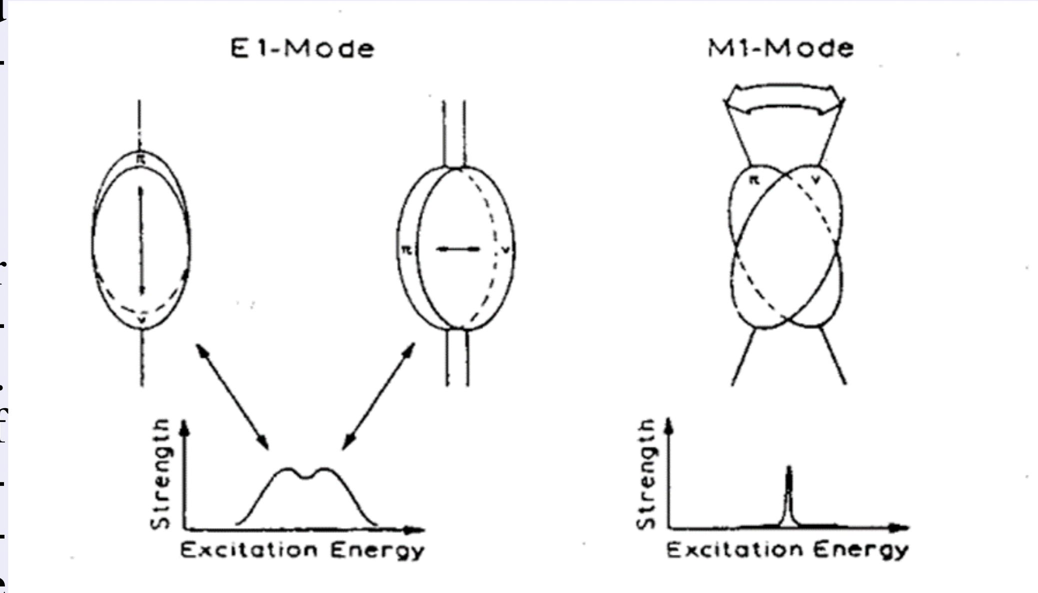
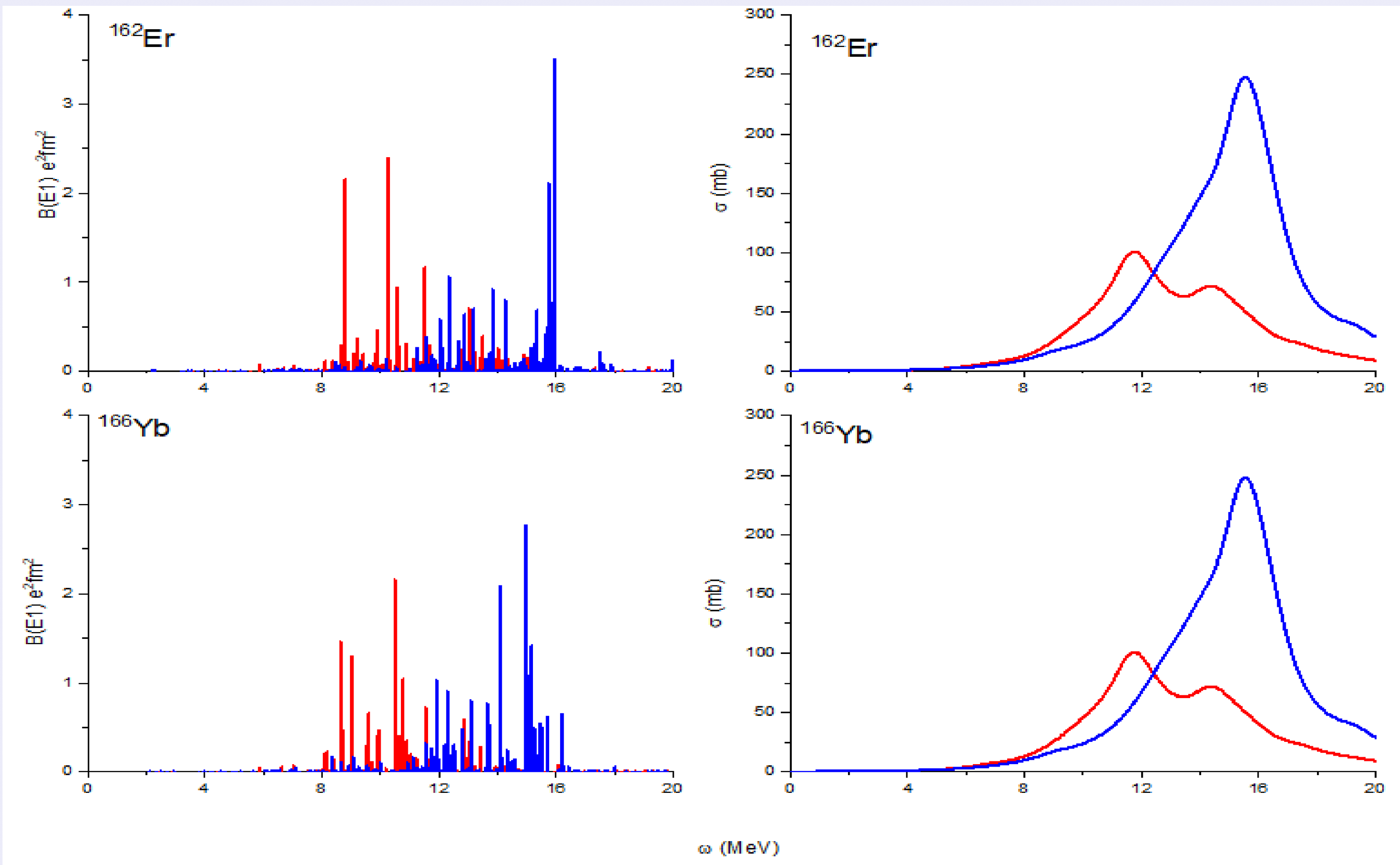


Fig 1. Demonstration of the collective vibrations of neutrons against protons by the classic two fluids, leading to the isovector E1 and M1 modes.

Results

The calculations for the even-even ^{162}Er and ^{166}Yb nuclei were performed within the QRPA framework using a deformed Woods–Saxon potential. The neutron (proton) pairing parameters Δ_n (Δ_p) and chemical potentials λ_n (λ_p) were determined according to Soloviev's method (Soloviev, 1976), while the mean-field deformation parameters δ_2 were calculated according to (Bohr ve Motelson, 1975) using the experimental quadrupole moments (Raman, 2001).

Nuclei	Δ_n	Δ_p	λ_n	λ_p	β_2
^{162}Er	1.07	1.09	-8.327	-5.559	0.3222
^{166}Yb.	1.01	0.98	-8.504	-4.923	0.315



Conclusions

Based on our calculations, the following results were obtained.

1- Our calculation shows that the splitting of K=0 and K=±1 modes due to the deformed structure of ^{162}Er-^{166}Yb nuclei. (This splitting is clearly seen in the energy versus B(E1) and photo-absorption cross-section graphs given above).

2- E1 excitations in GDR regions (above the 8 MeV) display a stronger collective structure than low-lying and PDR energy regions.

3. The calculation revealed that the symmetrical behavior tends to continue through high-lying excitations in the pseudo mirror nuclei.

4. There are no experimental studies on the photoabsorption cross-sections of ^{162}Er and ^{166}Yb. The photoabsorption cross-section graphs of the two nuclei were compared with each other as seen above. The calculated photoabsorption cross-section confirms that these two nuclei having similar structures.

5. The calculations also show that particle-hole symmetry plays a key role not only in the low-lying levels but also in high lying levels.

6. We believe that our calculations will shed light on future experimental works.

7. We recommend taking into account particle-hole symmetry and consider the PMN concept for future calculation.

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