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PYGMY DIPOLE RESONANCE IN SEMI-MAGIC ^{124}Sn ISOTOPE WITHIN FRAMEWORK OF SEMI-DEFORMED QRPA MODEL

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Abstract. In this study, the Quasiparticle Random Phase Approximation (QRPA) has been carried out to investigation of the dipole response below neutron separation energy for semi-magic ^{124}Sn nucleus. The semi-magic structure of the ^{124}Sn nucleus makes it possible to think about its deformed shape. Therefore, to describe the dipole excitations in the semi-magic ^{124}Sn nucleus, the spherical basis for proton system and the deformed axial symmetric basis for neutron system were used. The results of the summed B(E1) value of the 1^- excitations are in agreement with the experimental results. The calculations showed resonance like structure between 6-8.5 MeV energy intervals, which can be identified as pygmy dipole resonance. The calculations indicated that there are a few positive parity 1^+ states where their contributions are too small in in PDR region.

Keywords: *Electric Dipole (E1), semi-magic, ^{124}Sn, semi-deformed QRPA, PDR.*

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1. Introduction

During the past twenty years, interest of researches has been on investigation of electric dipole strength so-called Pygmy Dipole Resonance (PDR). This mode was first observed at neutron capture reaction (Bartholomew *et al.*, 1973; Metzeger, 1978a,1978b). Up to now, PDR mode has been observed in light and medium nuclei (Herzberg *et al.*, 1999; Zilges *et al.*, 2002; Volz *et al.*, 2006; Schwengner *et al.*, 2007; Endres *et al.*,2009; Savran *et al.*, 2013; Özel *et al.*, 2014). The properties of the PDR have been studied within many different theoretical approaches starting from early 90-ies (Chambers *et al.*, 1994; Ponomarev *et al.*,2014; Paar *et al.*, 2003; Tsoneva & Lenske, 2008; Quliyev *et al.*, 2016; Quliyev *et al.*,2017; Guliyev *et al.*, 2017; Guliyev *et al.*, 2020; Tabar *et al.*, 2020a,b).

The high density of low-lying dipole states in spherical nuclei can be explained only with taking into account higher phonon degrees (Tsoneva & Lenske, 2008; Ponomarev, 2014). Another explanation for the high density of levels in spherical nucleiwould be deformation. The nuclei with double magic numbers have a spherical form, but the nuclei which have one magic number (neutron or proton) may have deformation, which increases shifting far away from the magic numbers. In recent years, it is discussed whether the semi-magic nuclei are deformed or not (Guliyev *et al.*, 2010; Guliyev *et al.*, 2002; Wood *et al.*, 1992; Linnemann *et al.*,2003). The non-negligible variation of the deformation along the tin isotopic chain, extracted from the collectivity of the B(E2, $0^+ \rightarrow 2^+$) transition (Raman *et al*., 2001) and strong fragmentation of E1 strength in PDR region below threshold energy allows an in-depth test of the above considerations. The stable tin isotopes exhibit features partially associated with vibrational and partially with (moderately) deformed nuclei. Experimentally observation below particle threshold energy mainly interpreted in base of spherical nuclear models. But in Z=50 nuclei, the proton number is a magic number and therefore the proton system has a spherical form, but as the neutron number is different from the magic number the neutron system may have small deformation which can increase density of dipole states. There are too much theoretic investigations that used different spherical basis to investigate ^{124}Sn isotope (Tsoneva & Lenske, 2008). Take into above mentioned predictions it would be very interesting to investigate ^{124}Sn in deformed based approaches and to look behavior of PDR in case moderate deformation.

The present paper is devoted to the investigation of the role of the deformation in the formation of the electric dipole excitations below the particle threshold energy region and their contribution to the energy weighted sum rule. Therefore, here the results of calculation obtained in spherical mean field base QRPA, compared with calculated results where deformed mean field basis for neutron and spherical mean field basis for proton system is used for investigation E1 dipole strength distributions below particle threshold energy for ^{124}Sn nucleus. There, by the selection of suitable separable effective forces, within the QRPA without introducing additional parameters, translational, Galilean and rotational in variances are restored for the description of the E1 and M1 excitations. This method has been quite successful in explaining of the PDR in semi-magic N=82 nuclei (Guliyev *et al*., 2010) and ^{120}Sn nucleus (Quliyev e*t.al*., 2016). Here also the contribution of M1 states to spectrum and its overlapping with E1 also will be investigated in PDR region.

2. Theory

The model Hamiltonian which produces the electric dipole states that includes single quasiparticle Hamiltonian, dipole-dipole interaction term, restoring h_0 and h_Δ interactions (for transitional and Galilean symmetries) is considered as

$$H = H_{sqp} + h_0 + h_\Delta + W_1 \qquad (1)$$

where the interaction W_1 represents the coherent isovector dipole vibrations of protons and neutrons, the c.m. of the nucleus being at rest. According to (Guliyev *et al*., 2002; Guliyev *et al*., 2009), the translational invariance of the single-quasiparticle Hamiltonian can be restored with the aid of a separable isoscalar effective interaction of the form

$$h_0 = -\frac{1}{2\gamma_\mu}\sum_\mu [H_{sqp}, P_\mu]^+ [H_{sqp}, P_\mu] \qquad (2)$$

where P_μ is the spherical component of the linear momentum for the $J^\pi = 1^-$ excitations, and $\mu = 0,\pm1$. In order to restore the broken Galilean symmetry of the pairing potentials U_Δ, we add a term to eq. (1):

$$h_\Delta = -\frac{1}{2\beta}\sum_\mu [U_\Delta, R_\mu]^+ [U_\Delta, R_\mu] \qquad (3)$$

The coupling parameters

$$\gamma_\mu = \langle 0 | [P_\mu^+, [H_{sqp}, P_\mu]] | 0 \rangle \text{ and } \beta = \langle 0 | [R_\mu^+, [U_\Delta, R_\mu]] | 0 \rangle$$

are then determined by the mean-field and pairing potentials, respectively, where $R_\mu = \sum_{k=1}^{A} r_k Y_{lm}(\vartheta_k, \varphi_k)$ is the c.m. coordinate of the nucleus. For the translation invariant dipole-dipole interaction, we use the isovector form (Pyatov & Salamov, 1977; Baznat & Pyatov, 1975):

$$W_1 = \frac{3}{2\pi}\chi_1 \left(\frac{NZ}{A}\right)^2 (\vec{R}_n - \vec{R}_p)^2 \tag{4}$$

where χ_1 denotes an isovector dipole-dipole coupling constant and $\vec{R}_n, \vec{R}_p$ are the c.m. coordinates of the neutron and proton systems, respectively.

If assuming that the restoring isoscalar h_0 and the isovector h_1 interactions determined in Refs. (Kuliev *et al.*, 2000; Dietrich *et al.*, 1989) and the spin-spin forces generate the 1^+-states in the deformed nuclei, the model Hamiltonian representing t electric dipole states can be considered as:

$$H = H_{sqp} + h_0 + h_1 + V_{\sigma\tau} \tag{5}$$

Here, H_{sqp} is the Hamiltonian of the single-quasiparticle motion of the deformed nuclei and $V_{\sigma\tau}$ takes into account the spin-isospin interaction of the form:

$$V_{\sigma\tau} = \frac{1}{2}\chi_{\sigma\tau}\sum_{i \neq j}(\vec{\sigma}_i \cdot \vec{\sigma}_j)(\vec{\tau}_i \cdot \vec{\tau}_j) \tag{6}$$

where, $\vec{\sigma}$ and $\vec{\tau}$ are the Pauli matrices that represent the spin and the isospin operators, respectively.

According to Refs. (Kuliev *et al.*, 2000; Dietrich *et al.*, 1989) the rotational invariance of the single-quasiparticle Hamiltonian can be restored with the aid of a separable isoscalar and isovector effective interactions of the form:

$$h_0 = -\frac{1}{2\gamma_0}\sum_\nu [H_{sqp} - V_1, J_\nu]^+ [H_{sqp} - V_1, J_\nu] \tag{7}$$

and

$$h_1 = -\frac{1}{2\gamma_1}\sum_\nu [V_1(r), J_\nu]^+ [V_1(r), J_\nu] \tag{8}$$

where

$$\gamma^{(\nu)} = \langle 0 | [J_\nu^+, [H_{sqp}, J_\nu]] | 0 \rangle, \quad \gamma_1^{(\nu)} = \langle 0 | [J_\nu^+, [V_1(r), J_\nu]] | 0 \rangle \tag{9}$$

and

$$\gamma^{(-1)} = \gamma^{(+1)} = \gamma,\ \gamma_1^{(-1)} = \gamma_1^{(+1)} = \gamma_1,$$
$$\gamma_0 = \gamma - \gamma_1,\ \gamma = \gamma_n + \gamma_p,\quad \gamma_1 = \gamma_{1n} - \gamma_{1p} \tag{10}$$
$$\gamma_\tau = 2\sum_{ss'}{}^{(\tau)} \varepsilon_{ss'} L_{ss'}^2 j_{ss'}^2 \quad \gamma_{1\tau} = 2\sum_{ss'}{}^{(\tau)} (V_1)_{ss'} L_{ss'}^2 j_{ss'}^2$$

Here, $J_\nu = J_\nu^n + J_\nu^p$ are the spherical components of the angular momentum ($\nu = \pm 1$), $\varepsilon_{ss'} = \varepsilon_s + \varepsilon_{s'}$ and ε_s are the energies of the deformed single-quasiparticle states $|s>$. The expression $L_{ss'} = u_s v_{s'} - u_{s'} v_s$ is defined in the usual Bogolyubov notation. The single-particle matrix elements for spin (s_{+1}) and angular momentum operator (j_{+1}) are denoted by $s_{ss'}$ and $j_{ss'}$, respectively.

3. Results and Discussions

Here the results of calculation obtained in spherical mean field base QRPA, compared with the results of calculations where deformed mean field basis for neutron and spherical mean field basis for proton system for ^{124}Sn nucleus. Where the single-particle energies were obtained on the spherical basis for protons and on the deformed axially symmetric basis for neutrons by using Woods-Saxon potential code (Dudek & Werner, 1978) with using the mean field deformation parameters β_2 defined from experimental quadrupole moments (Raman *et al*., 2001).The basis contained all discrete and quasi-discrete levels in the energy region up to 6 MeV. The pairing interaction constants taken from Soloviev (Soloviev, 1976) are based on single-particle levels corresponding to the nucleus studied. Δ_n=1.24 MeV and Δ_p=1.00 MeV pairing gap parameters were taken from Soloviev (Soloviev, 1976), the λ_n=-6.588 MeV and λ_p=-10.103 MeV chemical potentials were calculated. Besides, the model contains a single parameter only for the calculation of E1 transitions. The calculation for the E1 excitation was performed using a dipole-dipole interaction parameter $\chi_1 = 300 / A^{5/3} MeVfm^{-2}$ (Pyatov & Salamov, 1977; Ertugral *et al.*, 2009). Dipole-dipole interaction parameter value is in close agreement with the analysis of Bohr and Mottelson (Bohr & Mottelson, 1975). For M1 excitations, the isovector spin–spin interaction strength was chosen to $\chi_{\sigma\tau}$ = 30/A MeV (Kuliev *et al.*, 2000).

The advantage of using the deformed base for describing of E1 excitations is demonstrated by the comparison of the results obtained via the spherical and deformed based QRPA. Obtained results compared with observed ones (Govaert, 1998). As some of experimentally observed states are parity is unknown, here compared reduced transition widths of the low-lying E1 and M1 dipole excitations. The reduced dipole transition width is especially useful in the case, where experimentally parity determination of the individual excitations becomes quite difficult. The ground-state transition widths Γ_0 for the E1 and M1 transitions can be calculated using the following formulas:

$$\Gamma_0(E1) = 0.349 \cdot \omega_i^3 \cdot B(E1) \tag{11}$$

and

$$\Gamma_0(M1) = 3.86 \cdot \omega_i^3 \cdot B(M1) \tag{12}$$

In the 5-8.4 MeV energy region, the spherical QRPA model anticipated thirty-two electric dipole states with B(E1)=0.039 e^2fm^2. Where the semi-deformed QRPA calculations predicts sixty-three electric dipole states with summed B(E1)=0.358 e^2fm^{2}in the same energy region. Where ninety-one states with the summed B(E1)=0.379(45)e^2fm^2 were observed in the experiment (Govaert, 1998). As can be seen both the number of excitation and their summed strengths calculated in semi-deformed base are greater than those calculated in the spherical base.

It is evidently the calculation within semi-deformed QRPA model is better to describe the experimental observation and main aspects have an agreement with experimental data.

The results of the spherical and semi-deformed based QRPA calculations and available experiment data up to neutron separation energy for dipole excitations are presented in Figure 1. As can be seen the present calculation predicts strongly fragmented E1 states in the 6.5-8.4 MeV. Our calculation is showing electric dipole excitations concentrated in the two well-separated groups: first group at the low energies around 6.5 MeV and the second one at the high energies around 7.2-8.4 MeV. Similarly, experimental studies for the ^{124}Sn nucleus have reported that E1 states concentrates in two groups: at the low energy groups (below 7.2 MeV) and at the high energy groups (above 7.2 MeV) (Govaert, 1998). It is in good agreement with the findings of reference (Enders et al., 2012). Furthermore, the calculations anticipated that the high energy part is divided into three small groups around 7.5 MeV, 8 MeV and 8.5 MeV.

The increase in the number of excitations can be explained by the role of the deformation. Because, when the mean-field is deformed, the j-shells split with respect to the magnetic quantum number K and this, in turn, leads to the splitting of the spherical spin 1-states and to mixing of the states of multiples.

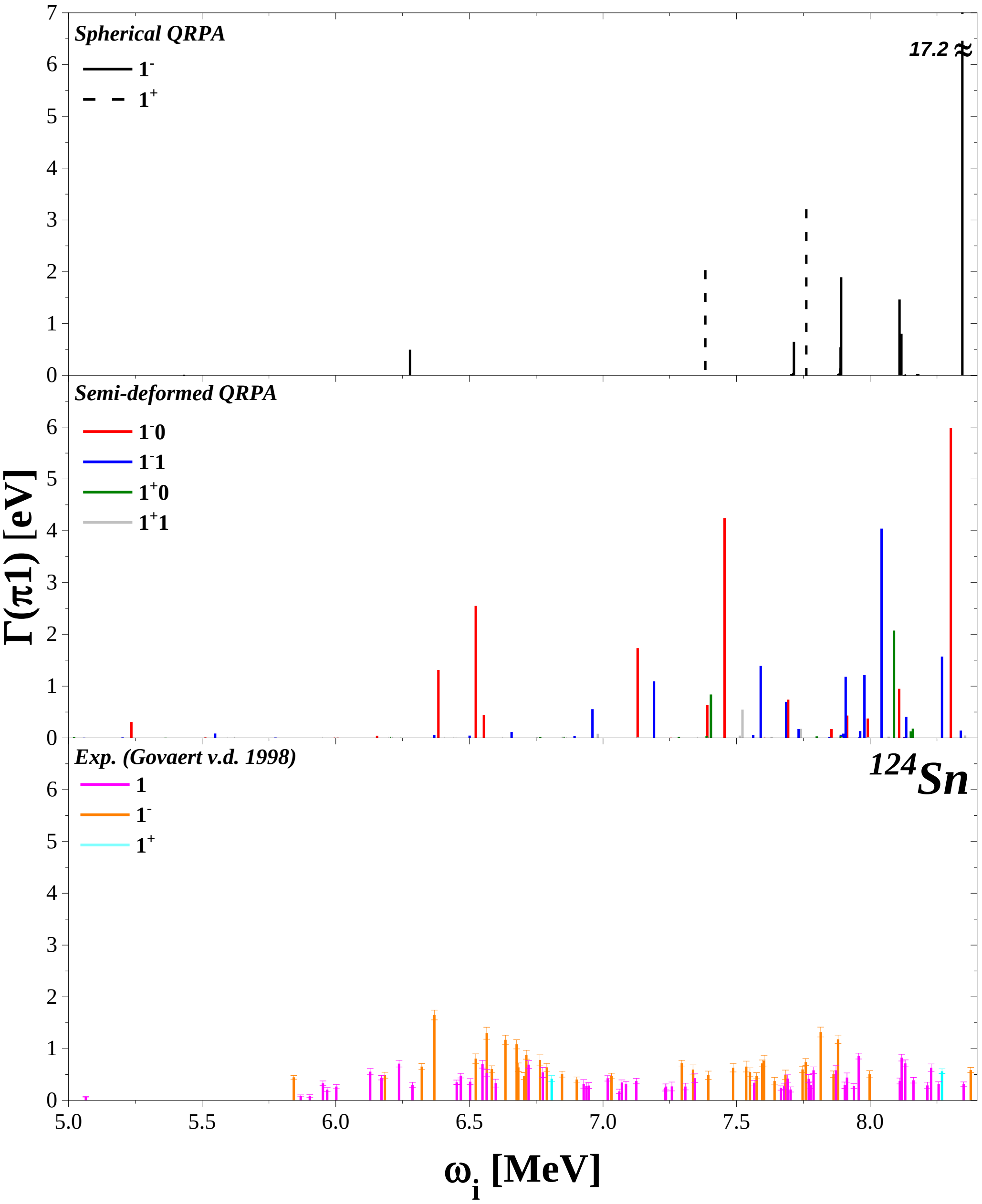

Figure 1. Comparison of the B(E1) values calculated in the spherical and semi-deformed based QRPA calculations with the experimentally (Govaert *et al.*, 1998) observed electric dipole excitations for ^{124}Sn

As can be seen from Figure 1, the calculations showed that in ^{124}Sn nucleus, K=0 components of E1 states were collected around 6.5 MeV, 7.5 MeV, and 8.5 MeV. Where, K=1 component of the E1 states were gathered around 8 MeV, and 8.4 MeV. In particular, strong E1 transitions are calculated around 8.4 MeV. As can be seen from figure the number of calculated excitation states is just over a tenth of the experimental numbers and the transition strengths of excitations is greater than the experimentally observed ones. The reason for this discrepancy could be possible contributions from complex excitations beyond the QRPA, such as, for example, fragmented two-phonon quadrupole–octupole states.

It is well known that in cases where the multi-phonon configuration is included, each 1^-state carries only a small fraction of one-phonon configurations and, accordingly, its *B*(E1) value is much smaller and more fragmented than that of the QRPA. At the same time, the total *B*(E1) strength does not change considerably (Tsoneva & Lenske, 2008; Ponomarev, 2014).

It is also well known that there is a very wide M1 resonance so called as spin-flip resonance in the around particle threshold energy (see *Figure 2*). Investigation of this resonance and descriptions of transitions properties would be very useful for future experiments where parity determination is not always possible. Therefore, here to identify the contribution of the magnetic dipole strength to the spectrum in the energy region between 5 and 8.5 MeV is calculated. Since the units of the probability of the E1 and M1 transitions differ from each other, here we also compare the calculated ground-state transition widths, where both E1 and M1 transition have the same units (see Figure 2). In the figure purple and yellow histograms correspond to E1 and M1 excitations, respectively.

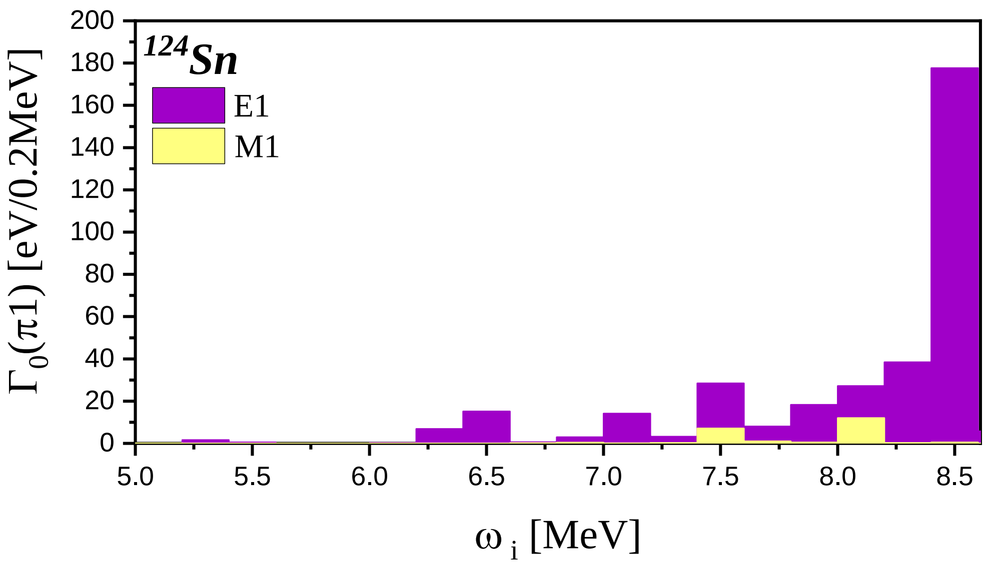

Figure 2. B(E1) (purple) and B(M1) (yellow) strength distributions for ^{124}Sn below the neutron threshold in 200 keV in comparison

As can be seen from the Figure 2, there is a clear spin-flip resonance distribution in the 5-8 MeV region for the ^{124}Sn nucleus. However, this distribution is not as pronounced as the PDR mode, but can be observed in experiments.

4. Conclusion

In summary, dipole strengths of ^{124}Sn nucleus below particle threshold energy was studied via transitional, Galilean and rotational invariant quasi particle random-phase approximation where paid particular attention comparison of spherical based QRPA results compared with results where takes proton system at the spherical base and neutron system at the deformed base below particle threshold energy. According to our calculations, the semi-deformed QRPA model is more successful in explaining the fragmentation and summed E1 strength in the PDR region. Our calculations show that the relative contribution of K=1 transition to the total dipole transition width below particle threshold energy is %46. The results that have been obtained for the summed B (E1) in the PDR region are in excellent agreement with the measured value by Govaert et al. (Govaert *et al.*, 1998). In addition, contribution of M1 levels was found to be low in PDR region.

References

Bartholomew, G.A., Earle, E.D., & Ferguson, A.J., Knowles, J.W., & Lone, M.A. (1973). Gamma-Ray Strength Functions. *Advances in Nuclear Physics*, 7, 229-324. doi:10.1007/978-1-4615-9044-6_4.

Baznat, M.I, & Pyatov, N.I. (1975). Transition densities and electroexcitation of nuclear dipole states. *Soviet Journal Nuclear Physics*, 21, 365.

Bohr, O., &Mottelson, B. (1975). *Nuclear Structure (Vol II)*, New York, Amsterdam.

Chambers, J., Zaremba, E., Adams, J.P., & Castel, B. (1994). *Physical Review C*, 50, R2671. doi:10.1103/PhysRevC.50.R2671.

Dietrich, K.G., Humbert, F., Richter, A., Brown, B.A., Kuliev, A.A., & Scholten, O. (1989). Magnetic dipole strength distribution at high excitation energies in deformed nuclei. *Physics Letters B*, 220, 351-355. doi: 10.1016/0370-2693(89)90886-1

Dudek, J., &Werner, T. (1978). New parameters of the deformed Woods-Saxon potential for A=110-210 nuclei. *Journal of Physics G: Nuclear Physics*, 4, 1543-1561.doi:10.1088/0305-4616/4/10/006/meta.

Endres, J., Savran, D., van den Berg, A.M., Dendooven, P., Fritzsche, M., Harakeh, M.N., Hasper, J., Wörtche, H.J., & Zilges, A. (2009). Splitting of the pygmy dipole resonance in ^{138}Ba and ^{140}Ce observed in the $(\alpha,\alpha'\gamma')$ reaction. *Physical Review C*, 80, 034302-0343010. doi:10.1103/PhysRevC.80.034302.

Endres, J., Savran, D., Butler, P.A., Harakeh, M.N., Harissopulos, S., Herzberg, R.-D., Krücken, R., Lagoyannis, A., Litvinova, E., Pietralla, N., Ponomarev, V.Yu., Popescu, L., Ring, P., Scheck, M., Schlüter, F., Sonnabend, K., Stoica, V.I., Wörtche, H.J., & Zilges, A. (2012). Structure of the pygmy dipole resonance in ^{124}Sn. *Physical Review C*, 85, 064331-064342. doi: /10.1103/PhysRevC.85.064331.

Ertugral, F., Guliyev, E., Kuliev, A.A., & Yildirim, Z. (2009). Fine structure of the dipole excitations of the even-even ^{160}Gd nucleus in the spectroscopic region. *Central European Journal of Physics*, *7*(4), 731-737. doi:10.2478/s11534-008-0155-5.

Govaert, K., Bauwens, F., Bryssinck, J., De Frenne, D., Jacobs, E., Mondelaers, W., Govor, L., Ponomarev, V. Yu. (1998). Dipole excitations to bound states in^{116}Snand^{124}Sn. *Physical Review C*, 57, 2229-2249. doi:10.1103/PhysRevC.57.2229.

Guliyev, E., Kuliev, A.A., von Neumann-Cosel, P., & Richter, A. (2002). Nature of the scissors mode in nuclei near shell closure: the tellurium isotope chain. *Physics Letters B*, 532, 173-178. doi:10.1016/S0370-2693(02)01555-1.

Guliyev, E., Kuliev, A.A., Ertugral, F. (2009). Low-lying magnetic and electric dipole strength distribution in the ^{176}Hf nucleus. *European Physics Journal A*, 39, 323-333. doi: 10.1140/epja/i2008-10722-3.

Guliyev, E., Kuliev, A.A., Guner, M., (2010). Electricdipole strength distribution below the E1giantresonancein N=82 nuclei. *Central European Journal of Physics*, 8, 961-969. doi:10.2478/s11534-010-0021-0.

Guliyev, E., Kuliev, A.A., & Quliyev, H. (2017). Pygmy dipole response in ^{238}U nucleus. *AIP Conference Proceedings*, 1815, 060010-060013. doi : 10.1063/1.4976406.

Guliyev, E., Quliyev, H., & Kuliev, A.A. (2020). *Journal of Physics G: Nuclear and Particle Physics*, 47, 115107-11524. doi: 10.1088/1361-6471/abaca0.

Herzberg, R.-D., Fransen, C., von Brentano, P., Eberth, J., Enders, J., Fitzler, A., Käubler, L., Kaiser, H., von Neumann–Cosel, P., Pietralla, N., Ponomarev, V. Yu., Prade, H., Richter, A., Schnare, H., Schwengner, R., Skoda, S., Thomas, H.G., Tiesler, H., Weisshaar, D., Wiedenhöver, I. (1999). *Physical Review C*, 60, 051307. doi:10.1103/PhysRevC.60.051307

Kuliev, A.A., Akkaya, R., Ilhan, M., Guliyev, E., Salamov, C., & Selvi, S. (2000). Rotational invariant model of the states with $K^{\pi}=1^{+}$and their contribution to the scissors mode. *International Journal of Modern Physics E*, 9, 249-261. doi:10.1142/S0218301300000179.

Kuliev, A. A., Guliyev, E., Ertugral, F., Ozkan, S. (2010). The low-energy dipole structure of ^{232}Th, ^{236}U and ^{238}U actinide nuclei. *European Physics Journal A*, 43, 313-321. doi:10.1140/epja/i2010-10933-y.

Linnemann, A., von Brentano, P., Eberth, J., Enders, J., Fitzler, A., Fransen, C., Guliyev, E., Herzberg, R.-D., Käubler, L., Kuliev, A.A., von Neumann-Cosel, P., Pietralla, N., Prade, H., Richter, A., Schwengner, R., Thomas, H.G., Weisshaar, D., & Wiedenhöver, I. (2003). Change of the dipole strength distributions between the neighbouring γ-soft nuclei ^{194}Pt and ^{196}Pt. *Physics Letters B*, 554(1-2), 15–20. doi:10.1016/s0370-2693(02)03235-5.

Metzger F.R. (1978a). Nuclear resonance fluorescence in ^{142}Nd. *Physical Review C*, 18, 1603-1608. doi:10.1103/PhysRevC.18.1603

Metzger F.R. (1978b). Nuclear resonance fluorescence in ^{138}Ba. *Physical Review C*, 18, 2138-2144. doi: 10.1103/PhysRevC.18.2138

Özel-Tashenov, B., Enders, J., Lenske, H., Krumbholz, A.M., Litvinova, E., von Neumann-Cosel, P., Poltoratska, I., Richter, A., Rusev, G., Savran, D., & Tsoneva, N. (2014). Low-energy dipole strength in ^{112,120}Sn. *Physical Review C*, 90, 024304.-024316. doi:10.1103/PhysRevC.90.024304

Paar, N., Ring, P., Niksic, T., & Vretenar, D. (2003). Quasiparticle random phase approximation based on the relativistic Hartree-Bogoliubov model. *Physical Review C*, 67, 034312-034326. doi:10.1103/PhysRevC.67.034312

Ponomarev V.Yu. (2014). Pygmy dipole resonance. XX International School on Nuclear Physics, Neutron Physics and Applications. *Journal of Physics: Conference Series*, 533, 012028-012031. doi:10.1088/1742-6596/533/1/012028

Pyatov, S.I., & Salamov D.I. (1977). Conservation laws and collective excitations in nuclei. *Nucleonica*, 22, 127-141.

Raman, S., Nestor, C.W., &Tikkanen, P. (2001). Transition probability from the ground to the first-excited 2^{+} state of even-even nuclides. *Journal Atomic Data and Nuclear Data Tables*, *78*(11), 1-128. doi:10.1006/adnd.2001.0858.

Quliyev,H., Zenginerler, Z., Guliyev, E., & Kuliev, A.A. (2016). Investigation of pygmy dipole resonance in ^{120}Sn, *App. Sci. Report.*, *14*(2), 199-201.

Quliyev, H., Guliyev, E., & Kuliev, A.A. (2017). Investigation of pygmy dipole resonance in ^{154}Sm. *AIP Conference Proceedings*, 1815, 060020-060023. doi: 10.1063/1.4976416.

Savran, D., Aumann, T., & Zilges, A. (2013). Experimental studies of the Pygmy Dipole Resonance. *Progress in Particle and Nuclear Physics*, 70, 210-245. doi:10.1016/j.ppnp.2013.02.003

Schwengner, R., Rusev, G., Benouaret, N., Beyer, R., Erhard, M., Grosse, E., Junghans, A.R., Klug, J., Kosev, K., Kostov, L., Nair, C., Nankov, N., Schilling, K.D., & Wagner A. (2007). Dipole response of ^{88}Sr up to the neutron-separation energy. *Physical Review C*, 76, 034321-034336. doi: 10.1103/PhysRevC.76.034321

Soloviev, V.G. (1976). *Theory of Complex Nuclei*. Pergamon Press. New York.

Tabar, E., Yakut, H., Kuliev, A.A., Hoşgör, G., Kemah, E., & Quliyev, H. (2020a). Investigation of the electric dipole (E1) excitations in ^{181}Ta nucleus. *European Physical Journal A*, 56, 271-281. doi: 10.1140/epja/s10050-020-00274-x.

Tabar, E., Yakut, H., Kuliev, A.A., Hoşgör, G., Kemah, E., & Quliyev, H. (2020b). Translational and Galilean Invariant Quasiparticle Phonon Nuclear Model (TGI-QPNM) for electric dipole (E1) transitions in odd-mass deformed nuclei. *Nuclear Physics A*, 1001, 121885-121908. doi: 10.1016/j.nuclphysa.2020.1218857

Tsoneva, N., Lenske, H. (2008). Pygmy dipole resonances in the tin region. *Physical Review C*, 77, 024321-024336. doi: 10.1103/PhysRevC.77.024321.

Volz, S., Tsoneva, N., Babilon, M., Elvers, M., Hasper, J., Herzberg, R-D., Lenske, H., Lindenberg, K., Savran, D., & Zilges, A. (2006). The photo-response of stable N=82 nuclei below 10 MeV. *Nuclear Physics A*, 779, 1-20. doi: 10.1016/j.nuclphysa.2006.08.012

Wood J. L., Heyde,K., Nazarewicz,W., Huyse, M., & van Duppen,P. (1992). Coexistence in even-mass nuclei. *Physics Report*, 215, 101-121. doi: 10.1016/0370-1573(92)90095-H.

Zenginerler, Z., Guliyev, E., Kuliev, A.A., Yakut, H., & Soluk, G. (2013). Systematic investigation of the low-lying dipole excitations in even-even $^{124-136}$Ba isotopes, *European Physics Journal A*, 49, 107. doi: 10.1140/epja/i2013-13107-7.

Zilges, A., Volz, S., Babilon, M., Hartmann, T., Mohr, P., & Vogt, K. (2003).Concentration of electric dipole strength below the neutron separation energy in N=82 nuclei, *Physics Letters B*, 542, 43. doi: 10.1016/S0370-2693(02)02309-2.