Investigation of pygmy dipole resonance in $^{120}$Sn

H.Quliyev¹, Z. Zenginerler¹, E. Guliyev², A.A. Kuliev³

¹1. Department of Physics, Faculty of Science and Art, Sakarya University, Sakarya, Turkey
²2. State Agency on Nuclear and Radiological Activity Regulation, Ministry of Emergency Situations, Baku, Azerbaijan
³3. The National Aviation Academy of Azerbaijan, Baku, Azerbaijan

**Abstract**

In this paper, QRPA with the translational and Galilean invariant Hamiltonian using spherical basis for protons and deformed axially symmetric basis for neutrons has been conducted to describe electric dipole excitations in semi-magic $^{120}$Sn nucleus. It has been shown that the main part of E1 strength, observed below the threshold in this nucleus may be interpreted as main fragments of the PDR. The results of the summed B(E1) value of the 1− excitations are good agreement with the experimental results. The calculation shown M1 excitations are too small and cannot concurrences with PDR.

**Keywords:** B(E1); Electric dipole; PDR; QRPA; $^{120}$Sn

**Introduction**

Pygmy Dipole Resonance (PDR) is currently a subject of high interest in nuclear physics, caused by recent significant experimental progress in studies of their properties in stable as well as in exotic neutron rich nuclei. The presence of the PDR was first observed at neutron capture reaction (Bartholomew et al., 1971; Metzger 1978 a,b). Then PDR mode has been experimentally found for isotopes ranging from the light nuclei (such as $^{17-22}$O) up to lead isotopes (Savran et al., 2013). Besides, recently observed the fundamental discrepancy between the $(\gamma,\gamma')$ and $(\alpha,\alpha'\gamma')$ data, i.e. a splitting of the PDR in two parts with different underlying structure for $^{140}$Ce and $^{138}$Ba provide a new challenge for model calculations (Savran et al., 2006; Enders et al., 2009). The investigation of PDR properties have been theoretically studied within many different theoretical approaches during the past twenty years (Ponomarev, 2014; Sarchi, 2004; Paar, 2003).

Sn nuclei have been studied a wide range both experimentally and theoretically. Recently, it is discussed if the nuclei which their one of the numbers of nucleon are not magic number are deformed or not (Guliyev et al., 2010; Guliyev et al., 2002; Wood et al., 1992). However, while the global properties of E1 strengths are reasonably understood in regions of moderate to large deformations, the nature of the electric dipole mode is an open question in semi-magic nuclei with neutron numbers near mid-shell shell. The non-negligible variation of the deformation along the tin isotopic chain, extracted from the collectivity of the B(E2, 0−→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 isotope chain exhibits features partially associated with vibrational and partially with (moderately) deformed nuclei.

The aim of the present work is to study the features of PDR of the $^{120}$Sn by using the QRPA method, where deformed axially symmetric basis used for neutron system. There, by the selection of suitable separable effective forces, within the QRPA without introducing additional parameters translational and Galilean invariances restored for the description of the E1 excitations. In our previous study, this method has been quite successful in explaining of the PDRinN=82 nuclei (Guliyev et al., 2010) and low lying electric dipole excitations up to 4MeV (Kuliyev et al., 2010). Here, the strength of the electric dipole excitations will be investigated below particle threshold energy for $^{120}$Sn nucleus. The contribution of K=0 and K=1 branches will be examined in PDR region and we are interested in not only the PDR resonance energy but also the contribution 0 and 1 states to none-energy weight sum rule of E1 excitations to PDR. Besides, we are also planning to investigate if PDR excitations overlap with the spin-flip M1 resonances or not.

**Theory**

According to ref. (Guliyev et al., 2002) the model Hamiltonian that produces the electric dipole 1− states in deformed nuclei that includes restoring $h_0$ and $h_3$ interactions for translational and Galilean symmetries is considered as
$H = H_{\text{qp}} + h_0 + h_{\Delta} + W_1$  
(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

$$h_0 = -\sum_{\mu} \frac{1}{2\gamma_{\mu}}[H_{\text{qp}}, P_\mu, H_{\text{qp}}, P_\mu]$$
(2)

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

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

The coupling parameters $\gamma_{\mu} = \langle 0 | [P_\mu, H_{\text{qp}}, P_\mu] | 0 \rangle$ and $\beta = \langle 0 | [R_\mu^+, U_{\Delta}, R_\mu] | 0 \rangle$ are then determined by the mean-field and pairing potentials, respectively, where $R_\mu = \sum_{k=1}^{A} r_k Y_{\delta_k} (\theta_k, \varphi_k)$ is the c.m. coordinate of the nucleus. For the translation invariant dipole-dipole interaction, we use the isovector form (Pyatov and Salamov, 1977; Baznat and Pyatov, 1975):

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

where $\chi_1$ denotes an isovector dipole-dipole coupling constant and $\bar{R}_n, \bar{R}_p$ are the c.m. coordinates of the neutron and proton systems, respectively.

**Results and Discussions**

For calculation of the E1 dipole transitions in the even–even $^{120}$Sn the mean field deformation parameters $\delta_2$ are calculated according to (Bohr and Mottelson, 1975) using deformation parameters $\beta_2$ defined from experimental quadrupole moments (Raman et al., 2001). Because of different shapes of the neutron and proton systems of $^{120}$Sn 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 and Werner, 1978). The basis contained all discrete and quasi-discrete levels in the energy region up to 6 MeV. This results in about one thousand two-quasiparticle dipole states for the each parity. The pairing-interaction constants taken from Soloviev (Soloviev, 1976) are based on single-particle levels corresponding to the nucleus studied. Values of the pairing quantities $\Delta$ and $\hat{\Delta}$ are shown in Table 1.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>$\Delta_n$</th>
<th>$\lambda_n$</th>
<th>$\Delta_p$</th>
<th>$\lambda_p$</th>
<th>$\delta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{120}$Sn</td>
<td>1.34</td>
<td>-7.683</td>
<td>1.00</td>
<td>-8.574</td>
<td>0.237</td>
</tr>
</tbody>
</table>

Besides, the model contains a single parameter only for the calculation of E1 transitions. The calculation for the E1 excitation was performed using a strength parameter $\chi_1 = 300/A^{5/3}$ MeVfm$^{-2}$ (Ertugral et al., 2009). Its magnitude is related to the isovector symmetry potential and the above value is in close agreement with the analysis of Bohr and Mottelson (Bohr and Mottelson, 1975). For M1 excitations, the isovector spin–spin interaction strength was chosen to $\chi_{\sigma\sigma} = 30/A$ MeV (Kaliev, 2000).

Theoretical calculations were performed in the interval energy 3-8.5 MeV as the same experimental energy range. The experiment predicts seventy three electric dipole 1 excitations with summed $\Sigma B(E1) = 0.253$ e$^2$fm$^2$. Where, the theory predicts totally sixty one electric dipole excitations with summed strength $\Sigma B(E1) = 0.253$ e$^2$fm$^2$. As can be seen, theoretical results are in very good agreement with the experimental results.

The theory predicts eighteen negative-parity $K=0$ states with summed $\Sigma B(E1) = 0.158$ e$^2$fm$^2$ and forty three $K=1$ states with summed $\Sigma B(E1) = 0.092$ e$^2$fm$^2$. Comparison has shown that fragmentation of K=1 branch much more than K=0 branch. Besides, summed B(E1) strength of K=0 branch is more than 1.7 times stronger than corresponding strength of K=1 branch. As a result, we can say that $\Delta K=0$ branch is much more dominant than $\Delta K=1$ branch in the PDR region. The QRPA results for E1 and M1 transition strengths up to an excitation energy of about 9 MeV are displayed in Fig. 1.
As can be seen from Figure 1, the experimental \(B(E1)\) values of these states are lower than \(0.01 \text{e}^2\text{fm}^2\). All \(1^-\) states are weakly collective. The small \(B(E1)\) values are characteristic of them. Among these states one can find a few \(1^-\) states with \(B(E1)>0.05 \text{e}^2\text{fm}^2\). Calculation for \(M1\) excitations showed that, they are located in same region with \(E1\).

Results have shown in Table 2 for both summed \(E1\) and summed \(M1\) excitations. As seen from table, the contribution of magnetic dipole states to the summed dipole states is about 13\%. Generally, electric and magnetic dipole states cannot be discriminated in NRF experiments (Govaert et al., 1998). Based on our results, we can say that the main contribution to total transition strength comes from \(E1\) levels in the energy region of the PDR.

**Table 2** Comparison of the summed \(B(E1)\) and \(B(M1)\) values calculated for \(^{120}\text{Sn}\) in units \(\text{e}^2\text{fm}^2\)

<table>
<thead>
<tr>
<th>(\sum B(E1)) ((\text{e}^2\text{fm}^2))</th>
<th>(\sum B(M1)) ((\text{e}^2\text{fm}^2))</th>
<th>Total dipole sum</th>
<th>(%) (B(E1))</th>
<th>(%) (B(M1))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.250</td>
<td>0.037</td>
<td>0.287</td>
<td>87</td>
<td>13</td>
</tr>
</tbody>
</table>

**Conclusion**

In our calculations, we used translational and Galileo invariant QRPA method which takes proton system at the spherical base and neutron system at the deformed base. The calculations showed resonance like structure between 7-8.5 MeV energy intervals, which can be identified as pygmy dipole resonance. Besides the agreement between calculated summed \(B(E1)\) values of \(1^-\) excitations and the available experimental data is quite good. In addition, contribution of \(M1\) levels was found to be low in PDR region.

**References**


Endres J, Savran D, van den Berg AM, Dendooven P, Fritzsche M, Hasper J, Wörnicke HJ, Zügsl A. 2009. Splitting of the pygmy dipole resonance in \(^{138}\)Ba and \(^{140}\)Ce observed in the \(^{138}\)Ce - \(^{140}\)Ba and \(^{140}\)Ce. Phys. Rev C 80: 034302.


