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Beta-transition properties for neutron-rich Sn and Te isotopes by Pyatov method

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Abstract. Based on Pyatov's method, the low-lying Gamow–Teller (GT) 1^+ state energies and log(ft) values for ^{128,130,132}Sb and ^{132,134,136}I isotopes have been calculated. In this method, the strength parameter of the effective spin–isospin interaction is found by providing the commutativity of the GT operator with the central part of the nuclear Hamiltonian. The problem has been solved within the framework of RPA. The calculation results have been compared with the corresponding experimental data.

Keywords. Gamow–Teller, RPA

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1. Introduction

The method developed by Pyatov and Cherney [1–3] has been applied to different problems for about thirty years. The main step of Pyatov's contraction is the definition of an effective Hamiltonian which incorporates Dirac's constraints [4] to the original symmetry breaking Hamiltonian. This method has been used previously to deal with the violation of the particle number [5], rotational invariance [6], generalized Galilean invariance [7] and velocity-dependent effects [8]. In ref. [9] this method has been applied to isospin-dependent Hamiltonians, written in the quasiparticle basis, in order to explore the link between the collapse of the RPA and the breakdown of the isospin symmetry. This method was used by Magierski and Wyss [10]. In refs [11–14], Pyatov's method was used to investigate scissor mode vibrations in deformed nuclei, IAR states and the isospin admixtures in the ground states for spherical nuclei, the GTR states in spherical nuclei etc.

In the present paper, based on shell model average field approximation, the β transition properties in near double close shell nuclei have been studied using Pyatov's method. Our aim in this study is to test the applicability of the method to the GT transitions for the nuclei in which the pairing interaction is negligible. In this respect, the strength parameter of charge exchange spin–spin interaction has been found from the commutativity of GT operator with the central part of

Table 1. Comparison of theoretical and experimental binding energies (in MeV) of the shell model states near Fermi surface for ^{132}Sn.

Neutron hole				Proton particle			
Level	Exp. [18]	This work	[17]	Level	Exp. [18]	This work	[17]
n1$g_{9/2}$	–	−14.789	−15.579	p1$g_{7/2}$	−9.654	−9.452	−9.497
n2$d_{5/2}$	−9.041	−10.056	−9.956	p2$d_{5/2}$	−8.691	−9.533	−9.345
n1$g_{7/2}$	−9.820	−9.592	−9.269	p1$h_{11/2}$	−6.860	−8.379	−7.695
n3$s_{1/2}$	−7.718	−8.044	−8.013	p2$d_{3/2}$	−6.945	−6.350	−7.402
n1$h_{11/2}$	−7.628	−7.317	−7.855	p3$s_{1/2}$	–	−6.676	−7.121
n2$d_{3/2}$	−7.386	−7.576	−7.737	p2$f_{7/2}$	–	−1.390	−0.921
	Neutron particle				Proton hole		
n2$f_{7/2}$	−2.445	−2.582	–	p2$p_{3/2}$	–	−17.700	−17.114
n3$p_{3/2}$	–	−1.044	−1.056	p2$p_{1/2}$	−16.131	−16.119	−15.865
n3$p_{1/2}$	–	−0.236	−0.563	p1$g_{9/2}$	−15.778	−15.894	−15.350

nuclear Hamiltonian. The energies of GT 1^+ excited states occurring in the neighbour odd–odd nuclei and the β decay $\log(ft)$ values have been calculated within the framework of RPA. These calculations have been done for ^{128,130,132}Sb and ^{132,134,136}I isotopes. Since there is no study based on other models for the investigated nuclei in literature the calculations based on schematic model in which the GT effective interaction is accepted as $\chi(\widehat{\sigma}\widehat{\sigma})(\widehat{\tau}\widehat{\tau})$ ($\chi = 5.2A^{-0.7}$) have been done by us. The obtained results using Pyatov's method (PM) and the schematic effective interaction method (SM) $\chi(\sigma\sigma)(\tau\tau)$ have been compared with the corresponding experimental data.

We are not discussing about the mathematical procedure since it is given in refs [13–15].

2. Results and discussions

In the numerical calculations, the Woods–Saxon potential with Chepurnov parametrization [16] has been used. All the discrete and quasistationary states and all the neutron and proton transitions changing the radial quantum number by $\Delta n = 0, 1, 2, 3$ have been included in the basis. The Ikeda sum rule is fulfilled with 1–1.5% accuracy.

In order to determine whether or not our single particle basis is reliable enough, we have compared our basis with the corresponding experimental data and other calculation results. The comparison of theoretical and experimental binding energies (in MeV) of the shell model states near Fermi surface for ^{132}Sn is given in table 1.

It is seen from table 1 that our basis is reliable enough.

Firstly, for ^{130}Sn $\longrightarrow$ ^{130}Sb transitions in ^{130}Sb nucleus, the dependence of the excited 1^+ state energies up to $Q_\beta = 2679$ keV and β-decay $\log(ft)$ values on the average field isovector parameter has been investigated. The results have been compared with the corresponding experimental data in figure 1. As seen from the

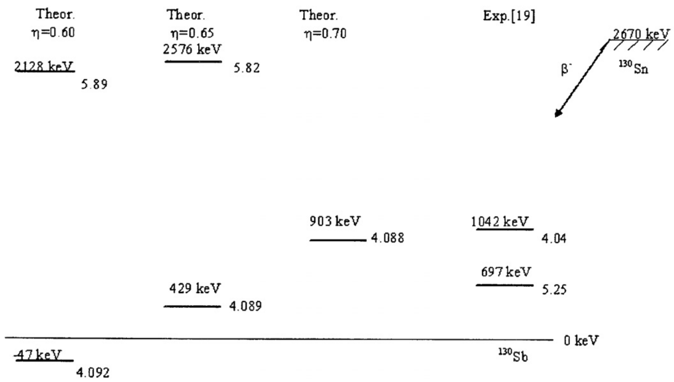

Figure 1. The dependence of β^--transition scheme ^{130}Sn $\rightarrow$ ^{130}Sb on the isovector parameter η.

figure (last column), there are two experimental 1^+ excited states in the energies 697 keV, 1042 keV with $\log(ft)$ values 5.25, 4.04 respectively. The results corresponding to $\eta = 0.60$, 0.65 and 0.70 values are displayed in the first, second and third columns of figure 1 respectively. For $\eta = 0.60$, two excited 1^+ states with the energies -47 keV ($\log(ft) = 4.092$) and 2128 keV ($\log(ft) = 5.89$) have been obtained in the mentioned energy region. As seen from the figure, the corresponding 1^+ states have higher energy values with the increase of the isovector parameter. However, the $\log(ft)$ values decrease slowly while the isovector parameter increases. This is really an expected result. The energy difference between neutron particle and proton hole levels forming the excited 1^+ state increases with the isovector parameter, but the $\log(ft)$ values do not change considerably since the increase of the isovector parameter has a negligible effect on the wave functions of the 1^+ states. Our results show that for $\eta = 0.70$, both the energy and $\log(ft)$ values are closer to the corresponding experimental data. (It is already very difficult to get a complete agreement for both the energy and $\log(ft)$ values between theory and experiment.) Therefore, isovector parameter has been taken as 0.70 in our calculations.

The energy and $\log(ft)$ values of low-lying (up to corresponding Q_{β^-} value) 1^+ states in ^{128,130,132}Sb and ^{132,134,136}I isotopes have been calculated using both methods and compared with the corresponding experimental data in figures 2 and 3 respectively. Both figures are divided into three parts: Calculation results for each isotope are given in different parts of the figure. The experimental values are shown in the first columns of each part and theoretical calculation results based on PM and SM are shown in the second and third columns respectively. As seen from the figure, only one 1^+ excited state at energy 635 keV with $\log(ft) = 4.44$ has been observed experimentally in β transition energy region in ^{128}Sb isotope (see first column). The calculation based on PM shows that there is an excited state at energy 472 keV with $\log(ft) = 4.06$. It should be noted that the mentioned 1^+ state mainly (70%) consists of $(2d^n_{5/2}2d^p_{3/2})$ configuration. The calculations based on SM show that there is one excited state at energy 1358 keV with $\log(ft) = 3.17$. It is seen that the calculated energy and $\log(ft)$ values by PM are closer to the corresponding experimental data compared with the schematic model.

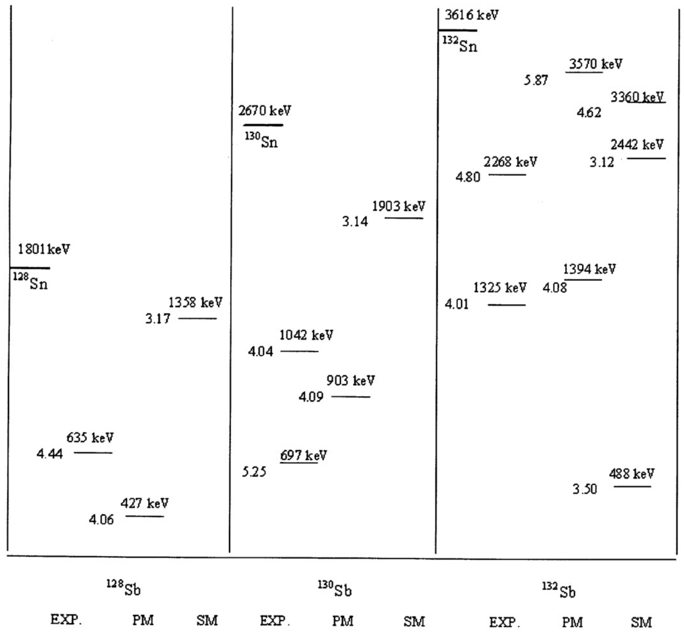

Figure 2. Comparison of the theoretical and experimental β-decay schemes for ^{128,130,132}Sn $\rightarrow$ ^{128,130,132}Sb.

The calculations done for ^{130}Sb isotope by PM show that the excited 1^+ state with the same structure $[70\%,(2d^n_{5/2}2d^p_{3/2})]$ occurs in 903 keV energy (see the middle part of the figure). The corresponding $\log(ft)$ value has been found to be 4.09. According to SM, the excited 1^+ state with the same structure has 1903 keV energy value ($\log(ft) = 3.14$). It is estimated that this excited state obtained theoretically may correspond to the experimental 1^+ state observed in 1042 keV energy ($\log(ft) = 4.04$). These values are closer to the calculated values by PM. The experimental 1^+ state at energy 697 keV ($\log(ft) = 5.25$) occurring in ^{130}Sb has not been obtained by both PM and SM.

The 1^+ state with the structure $(2d^n_{5/2}2d^p_{3/2})$ occurring in ^{132}Sb isotope has been determined in the energy 1394 keV ($\log(ft) = 4.08$) using PM and in the energy 2442 keV ($\log(ft) = 3.12$) using SM. The experimental 1^+ state with the energy 1325 keV ($\log(ft) = 4.01$) may correspond to the mentioned 1^+ state. The excited state with 2268 keV energy ($\log(ft) = 4.80$) observed in this isotope has been obtained in 3570 keV energy ($\log(ft) = 5.87$) and in 3360 keV ($\log(ft) = 4.62$) by PM and SM respectively.

Based on the theoretical calculations it is estimated that the experimental 1^+ states at 635 keV energy ($\log(ft) = 4.44$) occurring in ^{128}Sb isotope, at 1042 keV ($\log(ft) = 4.04$) occurring in ^{130}Sb isotope, at 1325 keV ($\log(ft) = 4.01$) occurring in ^{132}Sb isotope have the same structure $(2d^n_{5/2}2d^p_{3/2})$. It can be said that the calculations based on PM explain the experimental properties of these 1^+ states in the mentioned isotopes well. Neither PM nor SM has given any explanation for the

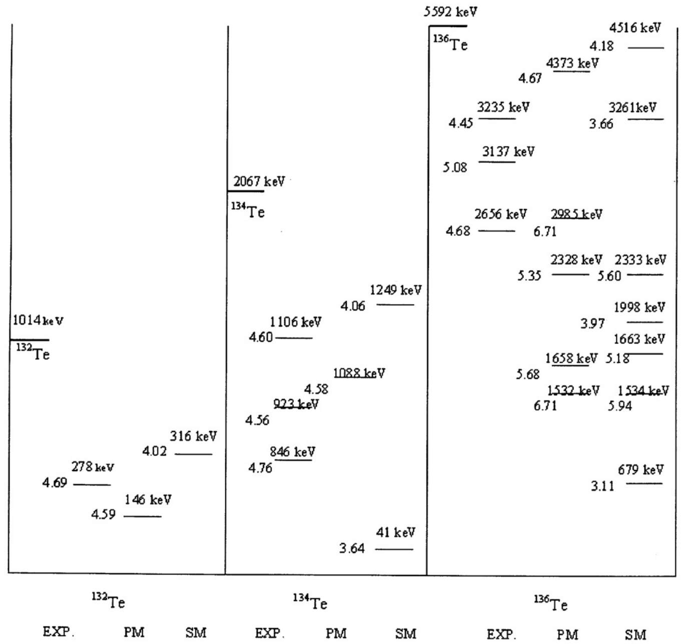

Figure 3. Comparison of the theoretical and experimental β-decay schemes for ^{132,134,136}Te $\rightarrow$ ^{132,134,136}I.

experimental 1^+ states at the energy 697 keV ($\log(ft) = 5.25$) in ^{130}Sb and 2268 keV ($\log(ft) = 4.80$) in ^{132}Sb isotopes.

In figure 3, similar results for ^{132,134,136}I isotopes are compared with the corresponding experimental data. The results obtained by PM show that the 1^+ states, in 146 keV ($\log(ft) = 4.59$) for ^{132}I isotope, in 1088 keV ($\log(ft) = 4.58$) for ^{134}I isotope and in 4373 keV ($\log(ft) = 4.67$) for ^{136}I isotope have the same structure. The results show that the mentioned 1^+ states are more collective and consist of $(2d^n_{3/2}2d^p_{5/2})$ and $(1h^n_{11/2}1h^p_{11/2})$ configurations. The contributions of these configurations are 64%, 36% in ^{132}I, 67%, 30% in ^{134}I and 77%, 22% in ^{136}I respectively. It can be said that the mentioned 1^+ states found by PM may correspond to those observed experimentally, in 278 keV ($\log(ft) = 4.69$) for ^{132}I, in 1106 keV ($\log(ft) = 4.60$) for ^{134}I, 2656 keV ($\log(ft) = 4.68$) for ^{136}I isotopes. The corresponding 1^+ states found by SM occur in 316 keV ($\log(ft) = 4.02$) for ^{132}I, in 1240 keV ($\log(ft) = 4.06$) for ^{134}I, in 4516 keV ($\log(ft) = 4.18$) for ^{136}I isotope. In ^{134}I isotope, the experimental 1^+ states at 846 keV energy ($\log(ft) = 4.76$) and 923 keV energy ($\log(ft) = 4.56$) have not been determined by both PM and SM. More than one excited state in theoretical calculations have been determined in ^{136}I isotope since Q_β energy value is large enough. The excited 1^+ states at 2357 keV energy ($\log(ft) = 5.35$) and 1658 keV ($\log(ft) = 5.68$) obtained by PM may correspond to the experimental 1^+ states at the energy 3235 keV ($\log(ft) = 4.45$) and 3137 keV ($\log(ft) = 5.08$). The results based on SM show that more excited states occur in the mentioned energy region and $\log(ft)$ values are in the range of 3.11–5.60. For

^{136}I isotope, the excited 1^+ states found in 1532 keV ($\log(ft) = 6.70$) and 2985 keV energy values ($\log(ft) = 6.71$) by PM may not be observed in experimental studies since their $\log(ft)$ values are very high.

3. Conclusion

As a result, the following conclusions can be obtained:

– The experimentally observed fact that the energies of low-lying 1^+ states increase with the increase of N-Z difference is confirmed by theoretical calculations. This is because the energy difference between neutron particle and proton hole states forming the low-lying 1^+ states increases while the isovector potential increases due to the increase in N-Z difference.

– The results based on PM provide a better explanation for the experimental 1^+ states with the smaller $\log(ft)$ values compared with the results of SM. Moreover, it is shown that the mentioned 1^+ states, occurring in ^{128,130,132}Sb isotopes, mainly consist of $(2d^n_{5/2}2d^p_{3/2})$ configuration, and which are occurring in ^{132,134,136}I isotopes are more collective and consist of $(2d^n_{3/2}2d^p_{5/2})$ and $(1h^n_{11/2}1h^p_{11/2})$ configurations.

– The increase of the number of excited 1^+ states stemming from the increase of the corresponding Q_{β^-} energy value with the increase in N-Z difference has been observed both theoretically and experimentally.

– The reason why the experimental 1^+ states with $\log(ft)$ value larger than five have not been obtained by both theoretical methods may be the exclusion of anharmonic terms (the interaction terms between bosons) in RPA used in this study.

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