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Study of High-spin States for ^{90,91,92}Y Isotopes by Using Oxbash Code

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Abstract: In this paper, calculations of ^{90,91,92}Y isotopes have been performed by application of nuclear shell model in the Gloeckner (Gl) model space for two different interactions (Gloeckner (Gl) and Gloeckner pulse bare G-Matrix (Glb) using Oxbash code. The energy levels are compared and discussed with experimental data and based on our results, many predictions about spins and parity were observed between experimental states, in addition to the predictions of low-energy spectra and B (E2; ↓) and B (M1; ↓)) transitional strengths in the isotopes ^{90,91,92}Y. These predictions were not known in the experimental data.

Keywords: Energy levels, Transition probabilities, Oxbash code.

Introduction

Numerous models have been developed to describe the nuclear structure; one of these models is the nuclear shell model (SM), which was introduced nearly 50 years ago by Mayer, Haxel, Jensen and Suess. This model has been very successful in describing the properties of various nuclei with few valence nucleons. These properties include energy levels, magnetic and electrical moments, the possibilities of electromagnetic transmission and the cross-section of various reactions [1, 2]. According to this model, the moement of each nucleus is subjected to an average attractive force of all other nucleons [3]. All the nucleons (protons or neutrons) in the nuclei are in filled shells according to the Pauli principle of exclusion and these numbers are called protons or neutrons with magic numbers which are (2, 8, 20, 28, 50, 82 and 126). The numbers are indicated on the nuclide diagram. Filled orbits have a total angular momentum (J) equal to zero; the next added nucleon (a valence nucleon) determines the J of the new ground state [4]. The basic inputs for SM calculations include individual particle energies and effective interactions, adapted to the specific model space and the nucleus containing only a small number of particles outside the closed core provides much information about the elements of the remaining reaction matrix [5]. The model space is usually defined by taking a few single-particle orbits near the Fermi surface [6].The success of nuclear shell model can explain many of the properties of the stable nuclides. For example, according to previous studies of low-lying states for nuclei near the ^{88}Sr region, like (^{89}Tc, ^{92}Rh and ^{94}Pd) isotopes, have been studied in (1997) by H. Herndl and B.A. Brown [7]. X. Ji and B. H. Wildenthal have reported on shell-model calculations for the isotopes with (A = 80 - 87) [8].

The present work aims to study the ^{90,91,92}Y isotopes' nuclear structure by applying the nuclear shell model that can be performed outside inert-core nuclei of ^{88}Sr with some valence nucleons distributed over the ($2p_{1/2}$ $1g_{9/2}$) for protons' model space and ($3s_{1/2}$, $2d_{5/2}$) for neutrons' model space.

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Theory

Shell model represents an important step to understand the nuclear structure and introduces a simple Hamiltonian, which is able to describe nuclear properties through an extensive range of nuclei and established general algebraic group theoretical methods. The shell model has become one of the most intensive nuclear models in use, due to its ability to describe the changing low-lying properties of nuclei across an entire major shell with a simple Hamiltonian [9]. The shell-model calculations with some nucleons outside of inert core can be considered as a success when describing a large subset of the observed energy levels and transitions for the nuclei covered by the model space with Hamiltonians and operators, which are close to the expected ones of the free nucleons properties [10]. Mainly, the success was in the residual interaction when using Gloeckner (Gl) and Gloeckner pulse bare G-Matrix (Glb) interactions of ^{90,91,92}Y isotopes which are close to sub-shell closure, thus it was expected to show single-particle characteristics [11].

A drastic simplification is offered by the basic properties of the nucleon interaction:

1- The attractive strong interaction is a short-range force: on the larger scale of the atomic description in 105 times, having a very small effect that can be neglected.

2- The saturation of the binding energy per nucleon around the (8 MeV) value indicates that the nucleons can interact with their nearest neighbors only [12].

Studying the low-lying excited states of closed shells and near-closed shells can provide information about a specific nuclear orbital nucleus, due to few nuclear orbits dominant in the contribution to their wave function. In case of the nuclei around ^{88}Sr region, the experimental and theoretical information available on neutron-rich variety is relatively limited [13].

In the nuclei, numbers of valence protons outside closed shell, moving in the orbits j_1, interact with valence neutrons numbers which fill a set of orbits j_2. The Hamiltonian can be written as:

$$H = \sum_{j_\pi} \varepsilon_{j_\pi} n_{j_\pi} + \sum_{j_v} \varepsilon_{j_v} n_{j_v} + V_{\pi\pi} + V_{vv} + V_{\pi v} \quad (1)$$

Here, ε_{j_π} and ε_{j_v} denote the single-particle energies corresponding to the orbits j_1 and j_2, respectively, n_j and n_j denote the number operators for protons and neutrons occupying orbits j_1 and j_2, respectively, while V_{pp}, V_{pn} and V_{nn} represent the residual interaction of two bodies between protons, (protons and neutrons) and neutrons, respectively, Eq. (1) can be reduced by neglecting all interactions V_{vv} of the valence neutron space and all interactions $V_{\pi\pi}$of the valence proton space except the remainder only (proton -neutron interactions) $V_{\pi v}$ [14]:

$$\boldsymbol{H} = \sum_{j_\pi} \boldsymbol{\varepsilon}_{j_\pi} \boldsymbol{n}_{j_\pi} + \sum_{j_v} \boldsymbol{\varepsilon}_{j_v} \boldsymbol{n}_{j_v} + \sum_{j_\pi, j_v} \langle j_\pi j_v | V | j_\pi j_v \rangle \quad (2)$$

where $\langle j_\pi j_v | V | j_\pi j_v \rangle$ *is* the average of matrix element. Eq. (2) can calculate the eigen values for excitation energies. The error ratio between the calculated values and the theoretical values for each energy level can be calculated according to the following equation:

$$\Delta(\%) = \left(\frac{E_{exp.} - E_{theor.}}{E_{exp.}}\right) \times 100 \quad (3)$$

The reduced electromagnetic transition probabilities between the initial-state(I_i) nuclear and final-state nuclear (I_f) are [15, 16]:

$$B(E2; I_i \to I_f) = \frac{1}{2I+1} (\langle I_f | T(E2) | I_i \rangle^2) \quad (4)$$

B(E2) is the reduced electric quadrupole transition probability.

$\langle I_f | T(E2) | I_i \rangle$ is the reduced electric matrix element and can be written in terms of the proton and neutron as follows:

$$\langle I_f | T(E2) | I_i \rangle = \sum_{t_z} e(t_z) \langle I_f || \hat{O} J (\vec{r}, t_z) || I_i \rangle \quad (5)$$

where $\langle I_f || \hat{O} J (\vec{r}, t_z) || I_i \rangle$ is the electric matrix element which is expressed as the sum of the products of the one-body density matrix (*OBDM*) times the single-particle matrix elements. The matrix element can be written in terms by assigning effective charges $e^{eff}(t_z)$ to the protons and neutrons which are out of closed shell:

$$\langle I_f | T(E2) | I_i \rangle = \sum_{t_z} e^{eff}(t_z) \langle I_f || \hat{O} J (\vec{r}, t_z) || I_i \rangle_{MS} \quad (6)$$

while the reduced magnetic dipole transition probability B(M1) is given by [15]:

$$B(M1; I_i \to I_f) = \frac{1}{2I+1} (\langle I_f | T(M1) | I_i \rangle^2) \quad (7)$$

Calculations and Discussion

The main aim of the present work is to study the nuclear structure of ^{90,91,92}Y isotopes by using oxbash code for Gl and Glb effective interactions and compare the theoretical results with the available experimental data. Oxbash code is a set of commands for carrying out SM calculations with dimensions up to about 100,000 in the(J-T) scheme and about 2,000,000 in the (JM)-scheme, by applying the (2005-8) version of this code which can be used in any ordinary (PC) [13-15]. Oxbash code is described as a set of model spaces and interactions of shell-model calculations for various elements in the periodic table. In order to use this code, first, the model space and interaction should be specified; in other words, after choosing the appropriate model space of valence nucleons. This code constructs a set of possible ground states and then makes (JT) matrix based on linear combination of ground states which give suitable (T) and (J) values. Finally, by choosing the desirable interaction potential, the Hamiltonian of the problem is constructed and calculations are carried out, as a default giving the10 lowest energies [16, 17]. The applied model space illustrates the orbits which are considered in calculations using main shells in shell-model theory. The yttrium isotopes ^{90,91,92}Y with Z = 39 and N≥51, that have situated the nucleons above the semi-magic Sr (Z = 38, N = 50) nucleus, are important for testing the nuclear shell model.

Energy Levels

In this research, calculations have been achieved by employing the Oxbash code in the Gl model space which comprised the ($2p_{1/2}$ $1g_{9/2}$) for protons and ($3s_{1/2,}$ $2d_{5/2}$) for neutrons as valence orbits outside the semi-magic nucleus ($^{88}_{38}Sr_{50}$). In an extreme single-particle approach, the proton in ($2p_{1/2}$) orbit and the neutron in ($3s_{1/2}$) orbit are expected to determine the ground state of the nuclei ($^{89}_{39}Y_{50}$) and ($^{89}_{38}Sr_{51}$), respectively. The single particle energies of nuclei ($^{89}_{39}Y_{50}$) and ($^{89}_{38}Sr_{51}$) are {$2p_{1/2}$ (p) = -7.124; $1g_{9/2}$(p) = -6.248; $3s_{1/2}$(n) = -5.506 and $2d_{5/2}$(n) = -6.338}, respectively. Two effective interactions have been employed with Gl model space of the calculation of energy levels and electromagnetic transition probabilities. It should be indicated here that ^{90}Y nucleus has only isoscalar T = 0, wihle ^{91,92}Y have T=0.5 and 1, respectively. Table 1 presents the comparison between the results for Gl and Glb effective interactions, the available empirical energy levels and the error ratio of (^{90}Y) nucleus energy levels [18]. The (^{90}Y) nucleus has 39 protons and 51 neutrons; i.e., one proton and one neutron outside ($^{88}_{38}Sr_{50}$) close core; by using (Glb) interaction, the sequence order for the excitation energy levels is well reproduced with experimental values also showing good correspondence with the experimental values for {2_1^-, 3_1^-, 7_1^+ and 2_1^+} spins. Theoretically, in both interactions, the spins {3_1^+, 5_1^+, 4_1^+, 5_2^+, 4_2^+} for empirical values {0.953, 1.046, 1.189, 1.962 and 2.021} MeV, respectively, which have been unidentified experimentally, also have been in reasonable agreement with the theoretical values. Experimental value (1.298 MeV) has been predicted and affirmed by the (6) spin, which agrees with theoretical energies {1.323 and 1.382} MeV for both (Glb) and (Gl) interactions. By using the (Gl) interaction, the order of {2_1^+ and 7_1^+} spins is reversely predicted. Also, the predicted {4_1^+ and 5_1^+} spins that have been located above the {3_1^+ and 0_1^-} spins are in comparison with experimental data. These values are rather close to theoretical energies. While in (^{91}Y) nucleus, there is one proton and two neutrons above ($^{88}_{38}Sr_{50}$) close core. The comparison between theoretical energy levels and experimental data is displayed in Table 2 [19]. The order of {$1/2_1^-$, $9/2_1^+$, $3/2_1^-$, $5/2_1^-$ and $7/2_1^-$ } spins is well reproduced by the two interactions and the experimental states; these spins are predicted in agreement with energy values obtained with studied calculations. Some empirical values at energies {1.186, 1.485, 2.157, 2.761, 2.279, 2.572, 2.530, 2.689, 2.761, 3.100, 3.196 and 3.22} MeV have been confirmed with the spins {$7/2_1^-$, $13/2_1^+$, $17/2_1^+$, $15/2_1^+$, $5/2_2^+$, $7/2_2^+$, $5/2_3^-$, $7/2_2^-$, $15/2_2^+$, $9/2_4^+$, $11/2_3^+$, $9/2_5^+$ and $11/2_4^+$} at the studied theoretical results, where these values agreed with the studied results. A few high-spin levels for the experimental values {1.547, 1.579, 2.129, 2.158, 3.502 and 3.839} MeV have been identified with the spins {$9/2_1^-$, $5/2_1^+$, $7/2_1^+$, $3/2_2^-$, $7/2_4^+$ and $9/2_6^+$}, respectively by our theoretical predictions for the two interactions. New energy levels were predicted for (^{91}Y) nucleus; these values are unknown at experimental data. Similarly, for the (^{92}Y) nucleus, it can be assumed that one proton and three neutrons have been distributed beyond (^{88}Sr) core nucleus. Comparison between the experimental and theoretical energy levels is reported in Table 3 [20]. The comparison indicated that the ground state at both interactions has been well reproduced. Expected experimental values {0.310, 0.982, 0.780, 1.030, 1.310, 1.490, 1.690, 1.890, 2.07 and 2.3} MeV with the spins {3_1^-, 2_1^+, 0_1^-, 4_1^-, 1_1^-, 3_2^+, 4_3^+, 7_1^+, 3_3^-, 4_2^- and 4_3^-} were obtained by theoretical prediction. Spin (2) was confirmed with an experimental value of (0.430 MeV). New energy levels have been predicted for the ^{92}Ynucleus for both interactions that are unknown at experimental data.

TABLE 1. Comparison of the theoretical and experimental energy levels [18] for ^{90}Y nucleus by using Glb and Gl interactions.

Theo. Results for Glb Interaction		Exp. Results		Δ(%)	Theo. Results for Gl Interaction		Exp. Results		Δ(%)
E(MeV)	J^π	E(MeV)	J^π		E(MeV)	J^π	E(MeV)	J^π	
0.000	2_1^-	0.0	2^-	0	0.000	2_1^-	0.0	2^-	0
0.263	3_1^-	0.202	3^-	-30.19	0.227	3_1^-	0.202	3^-	-12.37
0.688	7_1^+	0. 681	7^+	-1.02	0.669	2_1^+	0.776	2^+	13.78
0.748	2_1^+	0.776	2^+	3.61	0.745	7^+	0. 681	7^+	-9.39
0.949	3_1^+	0.953	$2^+,\underline{3^+}$	0.41	0.959	5_1^+	1.046	$\underline{5^+},6^+,7^+$	8.31
1.011	0_1^-	1.211	0^-	16.51	1.000	3_1^+	0.953	$2^+,\underline{3^+}$	-4.93
1.059	5_1^+	1.046	$\underline{5^+},6^+,7^+$	-1.24	1.096	4_1^+	1.189	—	7.82
1.135	4_1^+	1.189	—	4.54	1.274	0_1^-	1.211	0^-	-5.20
1.168	1_1^-	1.371	1^-	14.80	1.382	6_1^+	1.298	$(5,\underline{6},7)^+$	-6.47
1.323	6_1^+	1.298	$(5,\underline{6},7)^+$	-1.92	1.560	1_1^-	1.371	1^-	-13.78
1.873	5_2^+	1.962	$\underline{5^+},6^+$	4.53	2.079	5_2^+	1.962	$\underline{5^+},6^+$	-5.96
1.998	4_2^+	2.021	—	11.38	2.196	4_2^+	2.021	—	-8.65

TABLE 2. Comparison of the theoretical and experimental energy levels[19] for ^{91}Y nucleus by using Gbl and Gl interactions.

Theo. Results for Glb Interaction		Exp. Results		Δ(%)	Theo. Results for Gl Interaction		Exp. Results		Δ(%)
E(MeV)	J^π	E(MeV)	J^π		E(MeV)	J^π	E(MeV)	J^π	
0.000	$1/2_1^-$	0	$1/2^-$	0	0.000	$1/2_1^-$	0	$1/2^-$	0
0.591	$9/2_1^+$	0.555	$9/2^+$	-6.48	0.616	$9/2_1^+$	0.555	$9/2^+$	-10.99
0.774	$3/2_1^-$	0.653	$3/2^-$	-18.52	0.718	$3/2_1^-$	0.653	$3/2^-$	-9.95
0.992	$5/2_1^-$	0.925	$5/2^-$	-7.24	0.904	$5/2_1^-$	0.925	$5/2^-$	2.27
1.280	$7/2_1^-$	1.186	$(7/2)^-$	-7.92	1.221	$7/2_1^-$	1.186	$(7/2)^-$	-2.95
1.544	$13/2_1^+$	1.485	$(13/2^+)$	-3.97	1.474	$5/2_1^+$	1.579	$\underline{5/2^+}, 7/2^+$	6.64
1.567	$11/2_1^+$	-----	-----	-----	1.559	$11/2_1^+$	-----	-----	-----
1.674	$9/2_1^-$	1.547	$7/2^-, \underline{9/2^-}$	-8.21	1.562	$9/2_1^-$	1.547	$7/2^-, \underline{9/2^-}$	-0.96
1.690	$5/2_1^+$	1.579	$\underline{5/2^+}, 7/2^+$	-7.02	1.850	$7/2_1^+$	2.129	$3/2, 5/2, \underline{7/2}$	13.10
1.814	$9/2_2^+$	-----	-----	-----	1.858	$13/2_1^+$	1.485	$(13/2^+)$	-25.11
1.906	$7/2_1^+$	2.129	$3/2, 5/2, \underline{7/2}$	.4710	1.903	$9/2_2^+$	-----	-----	-----
2.100	$17/2_1^+$	2.157	$(17/2^+)$	2.64	2.001	$15/2_1^+$	2.761	$(\underline{15/2},17/2)$	27.52
2.106	$5/2_2^-$	2.206	$5/2^-$	4.53	2.023	$3/2_1^+$	-----	-----	-----
2.150	$15/2_1^+$	2.761	$(\underline{15/2}, 17/2)$	22.12	2.144	$13/2_2^+$	-----	-----	-----
2.172	$3/2_2^-$	2.158	$\underline{3/2^-}, 5/2^-$	-0.64	2.169	$17/2_1^+$	2.157	$(17/2^+)$	-0.55
2.181	$1/2_1^+$	-----	-----	-----	2.191	$5/2_2^+$	2.279	$(\underline{5/2^+}, 7/2^-)$	3.86
2.191	$3/2_1^+$	-----	-----	-----	2.214	$1/2_1^+$	-----	-----	-----
2.264	$5/2_2^+$	2.279	$(\underline{5/2^+}, 7/2^-)$	0.65	2.337	$9/2_3^+$	-----	-----	-----
2.320	$7/2_2^+$	2.572	$(5/2^+, \underline{7/2}, 9/2^-)$	9.79	2.341	$5/2_2^-$	2.206	$5/2^-$	-6.11
2.367	$5/2_3^-$	2.530	$(5/2^-)$	6.44	2.500	$7/2_2^+$	2.572	$(5/2^+,\underline{7/2},9/2^-)$	2.79
2.391	$9/2_3^+$	-----	-----	-----	2.502	$3/2_2^-$	2.158	$\underline{3/2^-},5/2^-$	-15.94
2.458	$7/2_2^-$	2.689	$(\underline{7/2^-}, 9/2^-)$	8.59	2.515	$11/2_2^+$	2.631	-----	4.40
2.631	$11/2_2^+$	2.631	-----	0	2.519	$9/2_4^+$	3.100	$(9/2^-)$	18.74
2.653	$13/2_2^+$	-----	-----	-----	2.646	$5/2_3^-$	2.530	$(5/2^-)$	-4.58
2.724	$15/2_2^+$	2.761	$(\underline{15/2}, 17/2)$	1.34	2.767	$7/2_2^-$	2.689	$(\underline{7/2^-},9/2^-)$	-2.90
2.810	$5/2_3^+$	2.822	-----	0.42	2.908	$7/2_2^+$	-----	-----	-----
2.866	$3/2_2^+$	-----	-----	-----	2.909	$3/2_2^+$	-----	-----	-----
2.965	$7/2_3^+$	-----	-----	-----	2.982	$15/2_2^+$	2.761	$(\underline{15/2}, 17/2)$	-8.00

Theo. Results for Glb Interaction		Exp. Results		Δ(%)	Theo. Results for Gl Interaction		Exp. Results		Δ(%)
E(MeV)	J^π	E(MeV)	J^π		E(MeV)	J^π	E(MeV)	J^π	
2.971	$13/2_3^+$	-----	-----	-----	3.046	$5/2_3^+$	2.822	-----	-7.93
3.018	$9/2_4^+$	3.100	$(9/2^-)$	2.64	3.157	$11/2_3^+$	3.196	$(7/2^-, 9/2, \underline{11/2^+})$	1.22
3.077	$11/2_3^+$	3.196	$(7/2^-, 9/2, \underline{11/2^+})$	3.72	3.328	$13/2_3^+$	-----	-----	-----
3.150	$1/2_2^-$	3.045	$1/2^-$	-3.44	3.401	$13/2_4^+$	-----	-----	-----
3.180	$9/2_5^+$	3.227	$(\underline{9/2^+}, 11/2^+)$	1.45	3.442	$9/2_5^+$	3.227	$(\underline{9/2^+}, 11/2^+)$	-6.66
3.277	$11/2_4^+$	3.227	$(9/2^+, \underline{11/2^+})$	-1.54	3.608	$5/2_4^+$	-----	-----	-----
3.318	$5/2_4^+$	-----	-----	-----	3.629	$11/2_4^+$	3.227	$(9/2^+, \underline{11/2^+})$	-12.45
3.344	$13/2_4^+$	-----	-----	-----	3.663	$7/2_3^+$	3.502	$5/2^+, \underline{7/2}, 9/2^-$	-4.59
3.410	$7/2_4^+$	3.502	$5/2^+, \underline{7/2}, 9/2^-$	2.62	3.735	$1/2_2^-$	3.045	$1/2^-$	-22.66
3.899	$9/2_6^+$	3.839	$9/2^+, 11/2^+$	-1.56	4.362	$9/2_6^+$	3.839	$9/2^+, 11/2^+$	-13.62

TABLE 3. Comparison of the theoretical and experimental energy levels [20] for ^{92}Y nucleus by using Glb and Gl interactions.

Theo. Results for Glb Interaction		Exp.Results		Δ(%)	Theo.Results for Gl Interaction		Exp.Results		Δ(%)
E(MeV)	J^π	E(MeV)	J^π		E(MeV)	J^π	E(MeV)	J^π	
0.000	2_1^-	0	2^-	0	0.000	2_1^-	0	2-	0
0.224	1_1^-	-----	-----	-----	0.180	1_1^-	-----	-----	-----
0.263	3_1^-	0.310	$2^-,\underline{3^-},4^-$	15.16	0.227	3_1^-	0.310	$2^-,\underline{3^-},4^-$	26.77
0.396	2_2^-	0.430	$(2)^-$	7.90	0.324	2_2^-	0.430	$(2)^-$	24.65
0.603	4_1^+	-----	-----	-----	0.648	5_1^+	-----	-----	-----
0.639	3_1^+	-----	-----	-----	0.673	6_1^+	-----	-----	-----
0.641	6_1^+	-----	-----	-----	0.754	3_1^+	-----	-----	-----
0.762	7_1^+	-----	-----	-----	0.780	4_1^+	-----	-----	-----
0.768	5_1^+	-----	-----	-----	0.980	7_1^+	-----	-----	-----
0.862	5_2^+	-----	-----	-----	0.996	4_1^-	1.030	$2^-,3^-,\underline{4^-}$	3.30
1.022	2_1^+	0.892	≤ 3	-14.57	1.047	4_2^+	-----	-----	-----
1.052	0_1^-	0.780	$\underline{0^-},1^-,2^-$	-34.87	1.125	2_1^+	0.892	≤ 3	-26.12
1.060	4_1^-	1.030	$2^-,3^-,\underline{4^-}$	-2.91	1.237	0_1^-	0.780	$\underline{0^-},1^-,2^-$	-58.58
1.209	1_2^-	1.310	$0^-,\underline{1^-},2^-$	7.70	1.245	5_2^+	-----	-----	-----
1.388	6_2^+	-----	-----	-----	1.375	5_1^-	-----	-----	-----
1.463	2_2^-	-----	-----	-----	1.491	6_2^+	-----	-----	-----
1.485	3_2^+	1.490	$1^+,2^+,\underline{3^+}$	0.33	1.523	1_2^-	1.310	$0^-,\underline{1^-},2^-$	-16.25
1.499	5_1^-	-----	-----	-----	1.605	3_2^+	1.490	$1^+,2^+,\underline{3^+}$	-7.71
1.550	5_3^+	-----	-----	-----	1.687	2_2^+	-----	-----	-----
1.568	4_2^+	-----	-----	-----	1.718	2_2^-	-----	-----	-----
1.647	4_3^+	1.690	$3^+,\underline{4^+},5^+$	2.54	1.772	5_3^+	-----	-----	-----
1.740	1_3^-	-----	-----	-----	1.950	7_2^+	1.890	$5^+,6^+,\underline{7^+}$	-3.17
1.767	3_2^-	-----	-----	-----	1.959	3_3^+	-----	-----	-----
1.893	2_3^-	-----	-----	-----	1.965	9_1^+	-----	-----	-----
1.914	7_2^+	1.890	$5^+,6^+,\underline{7^+}$	-1.26	1.983	4_3^+	1.690	$3^+,\underline{4^+},5^+$	-17.33
1.954	8_1^+	-----	-----	-----	1.992	6_3^+	-----	-----	-----
1.970	9_1^+	-----	-----	-----	2.032	1_3^-	-----	-----	-----
1.972	3_2^-	2.07	$2^-,\underline{3-},4^-$	4.73	2.050	5_4^+	2.07	$2^-,\underline{3-},4^-$	0.96
2.025	4_2^-	2.07	$2^-,3-,\underline{4^-}$	2.17	2.082	8_1^+	2.07	$2^-,3-,\underline{4^-}$	-0.57
2.071	2_2^+	-----	-----	-----	2.089	3_2^-	2.07	$2^-,\underline{3-},4^-$	-0.91
2.081	1_1^+	1.383	1^+	-50.46	2.129	2_3^-	1.383	1^+	-53.94
2.089	0_1^+	-----	-----	-----	2.133	6_4^+	-----	-----	-----
2.114	3_3^+	-----	-----	-----	2.154	2_3^+	-----	-----	-----
2.129	6_3^+	-----	-----	-----	2.179	0_1^+	-----	-----	-----
2.216	7_3^+	-----	-----	-----	2.208	7_3^+	-----	-----	-----
2.220	4_4^+	-----	-----	-----	2.258	4_2^-	2.3	$\underline{4^-},5^-,6^-$	1.82
2.225	5_4^+	-----	-----	-----	2.275	1_1^+	1.383	1^+	-64.49
2.296	4_3^-	2.3	$\underline{4^-},5^-,6^-$	0.17	2.286	4_4^+	-----	-----	-----
2.328	6_4^+	-----	-----	-----	2.316	3_3^-	-----	-----	-----
2.411	3_4^+	-----	-----	-----	2.515	4_5^+	-----	-----	-----
2.418	2_3^+	-----	-----	-----	2.565	4_3^-	-----	-----	-----

Theo. Results for Glb Interaction		Exp.Results		Δ(%)	Theo.Results for Gl Interaction		Exp.Results		Δ(%)
E(MeV)	J^{π}	E(MeV)	J^{π}		E(MeV)	J^{π}	E(MeV)	J^{π}	
2.506	5_2^-	-----	-----	-----	2.577	3_4^+	-----	-----	-----
2.538	3_5^+	-----	-----	-----	2.641	1_2^+	2.9	1^+	8.93
2.559	4_5^+	-----	-----	-----	2.642	3_5^+	-----	-----	-----
2.580	6_5^+	-----	-----	-----	2.697	8_2^+	-----	-----	-----
2.621	5_5^+	-----	-----	-----	2.706	5_5^+	-----	-----	-----
2.670	4_6^+	-----	-----	-----	2.736	7_4^+	-----	-----	-----
2.728	7_4^+	-----	-----	-----	2.792	5_6^+	-----	-----	-----
2.730	5_6^+	-----	-----	-----	2.793	5_2^-	-----	-----	-----
2.733	8_2^+	-----	-----	-----	2.826	6_5^+	-----	-----	-----
2.735	2_4^-	-----	-----	-----	2.871	4_6^+	-----	-----	-----
2.740	1_2^+	2.9	1^+	5.51	2.895	4_7^+	-----	-----	-----
2.774	9_2^+	-----	-----	-----	2.967	9_2^+	-----	-----	-----
2.840	8_3^+	-----	-----	-----	2.969	3_6^+	-----	-----	-----
2.931	2_4^+	-----	-----	-----	3.028	2_4^+	-----	-----	-----
2.934	3_6^+	-----	-----	-----	3.079	5_7^+	-----	-----	-----
2.969	4_7^+	-----	-----	-----	3.096	7_5^+	-----	-----	-----
2.992	5_7^+	-----	-----	-----	3.167	8_3^+	-----	-----	-----
3.001	3_4^-	-----	-----	-----	3.263	6_6^+	-----	-----	-----
3.058	4_8^+	-----	-----	-----	3.312	5_8^+	-----	-----	-----
3.061	3_7^+	-----	-----	-----	3.318	2_4^-	-----	-----	-----
3.176	2_5^+	-----	-----	-----	3.372	4_8^+	-----	-----	-----
3.221	5_8^+	-----	-----	-----	3.410	3_7^+	-----	-----	-----
3.228	6_6^+	-----	-----	-----	3.416	2_5^+	-----	-----	-----
3.265	1_3^+	-----	-----	-----	3.550	3_4^-	-----	-----	-----
3.271	7_5^+	-----	-----	-----	3.611	6_7^+	-----	-----	-----
3.347	6_7^+	-----	-----	-----	3.653	1_3^+	-----	-----	-----
3.383	0_2^+	-----	-----	-----	3.838	0_2^+	-----	-----	-----
3.431	2_6^+	-----	-----	-----	4.083	5_9^+	-----	-----	-----
3.496	7_6^+	-----	-----	-----	4.090	7_6^+	-----	-----	-----
3.544	5_9^+	-----	-----	-----	4.199	3_8^+	-----	-----	-----
3.725	6_8^+	-----	-----	-----	4.236	2_6^+	-----	-----	-----
3.773	3_8^+	-----	-----	-----	4.280	6_8^+	-----	-----	-----
3.879	4_9^+	-----	-----	-----	4.417	4_9^+	-----	-----	-----

Electromagnetic Transition Probabilities

The transition rates are represented as a test for the most modern effective interactions that have been developed to describe odd-odd nuclei [17]. The electromagnetic transition probability values are calculated for all isotopes in this study by using the harmonic oscillator potential (HO, b), where (b›0) for all transitions in the ground band. Harmonic oscillator size values are {2.127, 2.131 and 2.135} fm at (^{90,91,92}Y) nuclei, respectively. Core polarization effects have been included by choosing the effective charges for proton {e_p = 0.350e}, but for neutron {e_n = 0.350e} for (^{90,91,92}Y) nuclei. While the values of parameters {gsp, gsn, glp, gln are equal to: 0.00, 1.000, -5.586, 3.826} at the magnetic transitions. New electromagnetic transitions of several *B(E2;↓) and B(M1;↓)* have been calculated by using oxbach code for (Glb) and (Gl) effective interactions of (^{90,91,92} Y) isotopes, as shown in Tables 4, 5 and 6, where there are no observations in the experimental data. This will add more information for the theoretical knowledge for all isotopes with respect to energy levels and electromagnetic transitions.

TABLE 4. The theoretical values for $B(E2;\downarrow)$ and $B(M1;\downarrow)$ transition strengths for ^{90}Y nucleus by using Glb and Gl interactions.

Theo.Results for Glb Interaction			Exp. Results	Theo. Results for Gl Interaction			Exp. Results
Spin Sequences	B(E2) e^2fm^4	B(M1) μ^2		Spin Sequences	B(E2) e^2fm^4	B(M1)μ^2	
$3_1^-\rightarrow 2_1^-$	0.9854	0.5565×10^{-2}	--------	$3_1^-\rightarrow 2_1^-$	0.9854	0.5565×10^{-2}	--------
$3_1^+\rightarrow 2_1^+$	50.17	4.044	--------	$5_1^+\rightarrow 7_1^+$	11.72	--------	--------
				$3_1^+\rightarrow 2_1^+$	50.17	4.044	
$0_1^-\rightarrow 2_1^-$	16.76	-------	--------	$3_1^+\rightarrow 5_1^+$	16.96	--------	--------
				$4_1^+\rightarrow 2_1^+$	1.187	--------	
$5_1^+\rightarrow 3_1^+$	12.70	--------	--------	$4_1^+\rightarrow 3_1^+$	32.33	2.484	--------
$5_1^+\rightarrow 7_1^+$	8.020	--------		$4_1^+\rightarrow 5_1$	0.3755	0.4224	
$4_1^+\rightarrow 2_1^+$	13.92	--------		$0_1^-\rightarrow 2_1^-$	16.76	--------	
$4_1^+\rightarrow 3_1^+$	19.66	3.842	--------	--------	--------	--------	--------
$4_1^+\rightarrow 5_1$	31.84	5.018		--------	--------	--------	
$1_1^-\rightarrow 0_1^-$	--------	0.6489		$6_1^+\rightarrow 7_1^+$	8.723	2.291	
$1_1^-\rightarrow 2_1^-$	3.724	--------	--------	$6_1^+\rightarrow 5_1^+$	19.27	2.468	--------
$1_1^-\rightarrow 3_1^-$	13.04	--------		$6_1^+\rightarrow 4_1^+$	1.005	--------	
$6_1^+\rightarrow 4_1^+$	10.30	--------		$1_1^-\rightarrow 0_1^-$	--------	0.6489	--------
$6_1^+\rightarrow 5_1^+$	18.33	3.375	--------	$1_1^-\rightarrow 3_1^-$	13.04	--------	--------
$6_1^+\rightarrow 7_1^+$	8.723	2.291		$1_1^-\rightarrow 2_1^-$	3.724	--------	--------

TABLE 5. The theoretical values for $B(E2;\downarrow)$ and $B(M1;\downarrow)$ transition strengths for ^{91}Y nucleus by using Glb and Gl interactions.

Theo.Results for Glb Interaction			Exp. Results	Theo. Results for Gl Interaction			Exp. Results
Spin Sequences	B(E2) e^2fm^4	B(M1) μ^2		Spin Sequences	B(E2) e^2fm^4	B(M1) μ^2	
$3/2_1^-\rightarrow 1/2_1^-$	6.966	-----	-----	$3/2_1^-\rightarrow 1/2_1^-$	6.659	-----	-----
$5/2_1^-\rightarrow 1/2_1^-$	7.010	-----		$5/2_1^-\rightarrow 1/2_1^-$	6.744	-----	
$5/2_1^-\rightarrow 3/2_1^-$	0.9774×10^{-2}	0.4503×10^{-2}	-----	$5/2_1^-\rightarrow 3/2_1^-$	0.5749×10^{-1}	0.4960×10^{-2}	-----
$7/2_1^-\rightarrow 3/2_1^-$	5.721	-----	-----	$7/2_1^-\rightarrow 3/2_1^-$	4.558	-----	-----
$7/2_1^-\rightarrow 5/2_1^-$	0.6711	-----		$7/2_1^-\rightarrow 5/2_1^-$	0.5592		
$13/2_1^+\rightarrow 9/2_1^+$	12.39	-----	-----	$5/2_1^+\rightarrow 9/2_1^+$	16.83	-----	-----
$11/2_1^+\rightarrow 9/2_1^+$	17.90	0.4710	-----	$11/2_1^+\rightarrow 9/2_1^+$	23.08	0.7018	-----
$11/2_1^+\rightarrow 13/2_1^+$	18.55	2.017					
$9/2_1^-\rightarrow 5/2_1^-$	5.415	-----	-----	$9/2_1^-\rightarrow 5/2_1^-$	5.092	-----	-----
$9/2_1^-\rightarrow 7/2_1^-$	0.2080	0.5937×10^{-2}		$9/2_1^-\rightarrow 7/2_1^-$	0.2080	0.5937×10^{-2}	
				$7/2_1^+\rightarrow 9/2_1^+$	0.5890×10^{-1}	0.9291	
$5/2_1^+\rightarrow 9/2_1^+$	15.59	-----	-----	$7/2_1^+\rightarrow 5/2_1^+$	35.87	3.605	-----
				$7/2_1^+\rightarrow 11/2_1^+$	10.03	-----	
$7/2_1^+\rightarrow 9/2_1^+$	0.1075×10^{-2}	0.7405		$13/2_1^+\rightarrow 9/2_1^+$	6.525	-----	
$7/2_1^+\rightarrow 5/2_1^+$	29.30	3.032	-----	$13/2_1^+\rightarrow 11/2_1^+$	16.68	1.164	-----
$7/2_1^+\rightarrow 11/2_1^+$	4.024	-----					
				$15/2_1^+\rightarrow 11/2_1^+$	5.885	-----	
$17/2_1^+\rightarrow 13/2_1^+$	8.971	-----	-----	$15/2_1^+\rightarrow 13/2_1^+$	0.2053×10^{-1}	0.3983×10^{-2}	-----
$15/2_1^+\rightarrow 13/2_1^+$	7.936	0.7259		$3/2_1^+\rightarrow 5/2_1^+$	5.462	0.3253×10^{-1}	
$15/2_1^+\rightarrow 11/2_1^+$	7.245	-----	-----	$3/2_1^+\rightarrow 7/2_1^+$	2.574	-----	-----
$15/2_1^+\rightarrow 17/2_1^+$	22.91	2.681					
$1/2_1^+\rightarrow 5/2_1^+$	26.77	-----	-----	$17/2_1^+\rightarrow 13/2_1^+$	8.196	-----	-----
$3/2_1^+\rightarrow 5/2_1^+$	0.1904	1.187		$1/2_1^+\rightarrow 5/2_1^+$	23.19	-----	
$3/2_1^+\rightarrow 7/2_1^+$	10.53	-----	-----	$1/2_1^+\rightarrow 3/2_1^+$	41.81	8.170	-----
$3/2_1^+\rightarrow 1/2_1^+$	24.68	6.899					

TABLE 6. The theoretical values for $B(E2; \downarrow)$ and $B(M1; \downarrow)$ transition strengths for ^{92}Y nucleus by using Glb and Gl interactions.

Theo. Results for Glb Interaction			Exp. Results	Theo. Results for Gl Interaction			Exp. Results
Spin Sequences	B(E2) e^2fm^4	B(M1) μ^2		Spin Sequences	B(E2) e^2fm^4	B(M1) μ^2	
$1_1^-\rightarrow 2_1^-$	17.30	0.4365×1^{-3}	--------	$1_1^-\rightarrow 2_1^-$	16.64	0.3598×1^{-3}	-----
$3_1^-\rightarrow 2_1^-$	0.3580×1^{-2}	0.5651×1^{-2}	--------	$3_1^-\rightarrow 2_1^-$	0.6072×1^{-3}	0.5689×1^{-2}	-----
$3_1^-\rightarrow 1_1^-$	2.124	--------	--------	$3_1^-\rightarrow 1_1^-$	2.055	--------	-----
$0_1^-\rightarrow 2_1^-$	6.295	--------	--------	$4_1^-\rightarrow 2_1^-$	5.344	--------	-----
				$4_1\rightarrow 3_1^-$	0.4035	--------	
$4_1^-\rightarrow 2_1^-$	5.137	--------	--------	$0_1^-\rightarrow 2_1^-$	7.881	--------	-----
$4_1^-\rightarrow 3_1^-$	0.3978	--------					
$5_1^-\rightarrow 3_1^-$	5.511	--------	--------	$5_1^-\rightarrow 3_1^-$	5.694	--------	-----
$5^-_1\rightarrow 4_1^-$	0.1188×1^{-1}	0.6216×1^{-2}		$5^-_1\rightarrow 4_1^-$	0.5013×1^{-2}	0.6150×1^{-2}	
$3_1^+\rightarrow 4_1^+$	52.84	4.041	--------	$6_1^+\rightarrow 5_1^+$	27.87	2.175	-----
$6_1^+\text{-}\rightarrow 4_1^+$	10.77	--------	--------	$3_1^+\rightarrow 5_1^+$	13.01	--------	-----
$7_1^+\rightarrow 6_1^+$	26.23	1.288	--------	$4_1^+\rightarrow 5_1^+$	0.1921	0.1128	-----
$5_1^+\rightarrow 6_1^+$	31.76	3.331	--------	$6_1^+\rightarrow 4_1^+$	9.890	--------	-----
$5_1^+\rightarrow 4_1^+$	7.311	1.220	--------	$4_1^+\rightarrow 3_1^+$	44.55	2.547	-----
$5_1^+\rightarrow 3_1^+$	12.34	--------	--------	$7_1^+\rightarrow 5_1^+$	0.1314×1^{-3}	--------	-----
				$7_1^+\rightarrow 6_1^+$	26.09	1.340	-----
$2_1^+\rightarrow 4_1^+$	0.3033	--------	--------	$2_1^+\rightarrow 3_1^+$	20.23	2.941	-----
$2_1^+\rightarrow 3_1^+$	39.35	4.298	--------	$2_1^+\rightarrow 4_1^+$	0.7037×1^{-1}	--------	-----
$8_1^+\rightarrow 6_1^+$	10.11	--------	--------	$9_1^+\rightarrow 7_1^+$	6.562	--------	-----
$8_1^+\rightarrow 7_1^+$	0.3438	0.5775×1^{-3}	--------	$8_1^+\rightarrow 6_1^+$	0.1709	--------	-----
$9_1^+\rightarrow 7_1^+$	6.461	--------	--------	$8_1^+\rightarrow 7_1^+$	9.138	0.6612×1^{-1}	-----
$9_1^+\rightarrow 8_1^+$	25.22	2.572	--------	$8_1^+\rightarrow 9_1^+$	0.7825	0.1028	-----
$1_1^+\rightarrow 3_1^+$	3.592	--------	--------	$0_1^+\rightarrow 2_1^+$	1.238	--------	-----
$1_1^+\rightarrow 2_1^+$	5.410	0.1320	--------	$1_1^+\rightarrow 3_1^+$	6.740	--------	-----
$0_1^+\rightarrow 1^+$	--------	34.23	--------	$1_1^+\rightarrow 2_1^+$	0.8048×1^{-2}	0.1553	-----
$0_1^+\rightarrow 2_1^+$	3.951	--------	--------	$1_1^+\rightarrow 0_1^+$	-------	6.605	-----

Conclusions

In this work, low-lying excited states in all isotopes provide valuable information on the interaction of valence neutrons and protons in nuclear structure. The nature of the neutron-proton residual interaction strongly affects the level order in the increase which arises from the configurations of neutrons and protons. The shell model succeeded in describing the low-lying states in a relatively small configuration space**.** The main objective of the nuclear structure focuses on two key questions: (i) can one consistently describe all three $^{90,91,92}Y$ isotopes within the Gl configuration space? (ii) do particle - particle excitations from the *Gl* space model play an increasingly important role when the number of neutrons increases? It is noticed that shell model configuration mixing has successfully evolved to study these energy levels. This is certainly the main challenge of nuclear structure experiments on odd–odd nuclei around double shell closures, which provides the best testing ground for the matrix elements of the proton–neutron interaction between valence nucleons. It was affirmed and identified that at the spins and parties, experimental values have been clear for several levels of all isotopes in this study. New values for energy levels and electromagnetic transitions {B(E2; ↓) and $B(M1; \downarrow)$}have been predicted for $^{90,91,92}Y$ isotopes, which are not indicated in the experimental data. It is concluded that more experimental data is required to fully investigate the level structure of these nuclei. The benefit of this work belongs to the Ministry of Higher Education and Scientific Research, especially the Faculty of Education for Girls, Department of Physics, noting that the subject of this work has not been previously studied in term of the investigated interactions by using the Oxbash code.

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