Mathematical and Computational Applications, Vol. 15, No. 1, pp. 79-88, 2010.

THE INVESTIGATION OF EVEN-EVEN $^{114\text{-}120}$Xe ISOTOPES BY THE FRAMEWORK OF IBA

İsmail Maraş[1*], Ramazan Gümüş[2] and Nurettin Türkan[3,4]
[1]Celal Bayar University, Faculty of Arts and Science, Manisa, Turkey
maras.ismail@yahoo.com
[2]Celal Bayar University, Institute of Science, Manisa, Turkey
ramazann_gumus@yahoo.com
[3]University of Wisconsin, Department of Physics, 53715 Madison, WI, USA
[4]Bozok University, Faculty of Arts and Science, 66200 Yozgat, Turkey
nurettin_turkan@yahoo.com

Abstract- In this work, the ground state, quasi beta and quasi gamma band energies of ^{114,116,118,120}Xe isotopes have been investigated by using the both (IBM-1 and IBM-2) versions of interacting boson model (IBM). In calculations, the theoretical energy levels have been obtained by using PHINT and NP-BOS program codes. The presented results are compared with the experimental data in respective tables and figures. At the end, it was seen that the obtained theoretical results are in good agreement with the experimental data.

Key Words- Interacting Boson Model, Even-Even Xe, Band Energies (Ground State, Quasi Beta and Quasi Gamma Band).

1. INTRODUCTION

One of the most remarkable simplicities of atomic nuclei is that the thousands of 2-body nucleonic interactions in a nucleus can be reduced to and simulated by a 1-body potential [1]. This is done with the interacting boson model (IBA) [2], which is a useful model to formalize description of symmetry in nuclei. This model (IBA) has a U(6) group structure leading to sub-groups chains denoted by U(5), SU(3) and O(6), which describe vibrational, axially symmetric rotational and γ-soft rotational nuclei. These three symmetries are denoted with a symmetry triangle called Casten triangle. Of course, most of the nuclei do not directly respect these exact symmetries. However, the symmetries allow us to locate simply any collective nucleus in the mapping procedure of triangle. The even-even nuclei in the region of Xe isotopes seem to be soft with regard to the γ deformation with an almost maximum effective trixiality of $\gamma \sim 30^{o}$ [3]. Zamfir et al. [4] stated that Xe isotopes of the mass region of $A \sim 130$ appear to evolve from U(5) to O(6)-like structure in the IBM. It is very difficult to treat them in terms of conventional mean field theories since they are neither vibrational nor rotational. The low-lying states showing a rich collective structure in this region were investigated extensively in terms of the pair-truncated shell model (PTSM) [5] and the relativistic Hartree-Fock Model (RHFM) [6]. The Xe [7–16], Ba [3,16–18] and Te [19–23] region with the mass number $A \sim 120$–130 has recently been studied experimentally and interpreted by several models [24–30]. In ref.[31], the general Bohr Hamiltonian (GBH) is applied to describe the low-lying collective excitations in even–even isotopes of Te, Xe, Ba, Ce, Nd and Sm, and the low-lying collective states of even–even nuclei is investigated along the region of $50 < Z, N < 82$. The ground state properties of even–even Xe isotopes have been the subject to theoretical [32] and experimental studies [33–40] involving in-beam γ -ray spectroscopy.

In the present study, the first and second versions of interacting boson model (IBM-1 and IBM-2) are used as a method of solution and new different parameter values of IBM-1 and IBM-2 are used to provide more detailed description on the neutron-rich 114-120Xe isotopes. So, the outline of the remaining part of this paper is as follows; starting from an approximate theoretical background of IBM-1 and IBM-2 for the Hamiltonian in section 2, the previous experimental [41] data are compared with calculated values of present study and the general features of Xe isotopes in the range N = 60-66 are reviewed in section 3. The last section contains some concluding remarks.

2. THEORETICAL BACKGROUND

As it has also been stated in [15,42–46], the IBM-2 Hamiltonian that has been used to calculate the level energies is [2],

$$H = \varepsilon_\nu n_{d\nu} + \varepsilon_\pi n_{d\pi} + \kappa Q_\pi Q_\nu + V_{\pi\pi} + V_{\nu\nu} + M_{\pi\nu} \tag{1}$$

where $n_{d\rho}$ is the neutron (proton) d-boson number operator.

$$n_{d\rho} = d^\dagger \tilde{d} \ , \rho = \pi, \nu$$
$$\tilde{d}_{\rho m} = (-1)^m d_{\rho,-m} \tag{2}$$

where $s^\dagger{}_\rho$, $d^\dagger{}_{\rho m}$ and $s_\rho, d_{\rho m}$ represent the s and d -boson creation and annihilation operators. The rest of the operators in the Eq. (1) are defined as

$$Q_\rho = (s_\rho^\dagger \tilde{d}_\rho + d_\rho^\dagger s_\rho)^{(2)} + \chi_\rho (d_\rho^\dagger \tilde{d}_\rho)^{(2)}$$
$$V_{\rho\rho} = \sum_{L=0,2,4} C_{L\rho} \left((d_\rho^\dagger d_\rho^\dagger)^{(L)} \cdot (d_\rho^\dagger \tilde{d}_\rho)^{(L)} \right)^{(0)} \qquad ; \ \rho = \pi, \nu \tag{3}$$

and

$$M_{\nu\pi} = \frac{1}{2} \xi_2 [(s_\nu^\dagger d_\pi^\dagger - d_\nu^\dagger s_\pi^\dagger)^{(2)} . (s_\nu \tilde{d}_\pi - \tilde{d}_\nu s_\pi)^{(2)}] - \sum_{L=1,3} \xi_L [(d_\nu^\dagger d_\pi^\dagger)^{(L)} . (\tilde{d}_\nu \tilde{d}_\pi)^{(L)}] \tag{4}$$

In this case $M_{\pi\nu}$ affects only the position of the non-fully symmetric states relative to the symmetric ones. For this reason $M_{\nu\pi}$ is often referred to Majorana force.

3. RESULTS AND DISCUSSION

In this section, the general features of Xe isotopes in the mass range of A = 114–120 are reviewed and it was seen that the presented results have better agreement with the experiment. Also, it can be stated that the detailed manner by which the mid-shell xenon isotopes acquire significant deformation is still unclear. In ref. [15], some of the energy results calculated by IBM are compared with the values obtained by PTSM approximation [47] for Xe isotopes in the range of A = 122–134. However, there is no many work studied for Xe isotopes in the range of A =114-120.

It must be stressed that the choice of parameters is undertaken iteratively by allowing one parameter to vary while keeping the others constant until an overall best fit was achieved for $^{114\text{-}120}$Xe nuclei. They are treated as free parameters that have been determined so as to reproduce as closely as possible the excitation-energy of all positive parity levels for which a clear indication of the spin value exists. Table 1 and 2 are showing such IBM-1 and IBM-2 parameters mentioned with the fit to the experimental data [41]. $^{114\text{-}120}$Xe isotopes have N_π = 2, and N_ν varies from 5 to 8, while the parameter values were estimated by fitting to the measured level energies.

Table 1 . The Hamiltonian parameters set used in the present study for the IBM-1 calculations of $^{114\text{-}120}$Xe nuclei.

^A_ZX	N	EPS	ELL	QQ	CHQ	OCT	HEX
$^{114}_{54}Xe$	7	0.931	-0.0053	-0.03	-1.2	-0.0011	-0.0078
$^{116}_{54}Xe$	8	0.649	-0.0020	-0.03	-1.1	-0.0011	-0.0078
$^{118}_{54}Xe$	9	0.639	-0.0059	-0.03	-1.1	-0.0011	-0.0078
$^{120}_{54}Xe$	10	0.666	-0.0030	-0.03	-1.1	-0.0011	-0.0078

Table 2. The Hamiltonian parameters set used in the present study for the IBM-2 calculations of $^{114\text{-}120}$Xe nuclei.

^A_ZX	N_π	N_ν	N	ε	κ	χ_ν	χ_π	$C_{L\nu}$ (L=0,2,4)	$C_{L\pi}$ (L=0,2,4)
$^{114}_{54}Xe$	2	5	7	0.926	-0.08	1.2	-1.2	0.00, 0.00,-0.07	0.0, 0.0, 0.0
$^{116}_{54}Xe$	2	6	8	0.613	-0.08	1.2	-1.2	0.00, 0.06, 0.05	0.0,-0.3, 0.0
$^{118}_{54}Xe$	2	7	9	0.567	-0.08	1.2	-1.2	0.00, 0.00, 0.06	0.0, 0.0, 0.0
$^{120}_{54}Xe$	2	5	7	0.926	-0.08	1.2	-1.2	0.00, 0.00,-0.07	0.0, 0.0, 0.0

The Hamiltonian sets of parameters which have been varied along the isotopic chain are shown as a function of the neutron number for $^{114\text{-}120}$Xe isotopes in Figure 1. In particular, the spectrum of the SU(5) nuclei is dominated by the value of ε, which is large in comparison with the other parameters, whereas O(6) nuclei are characterized by the value of κ, large compared to ε [48].

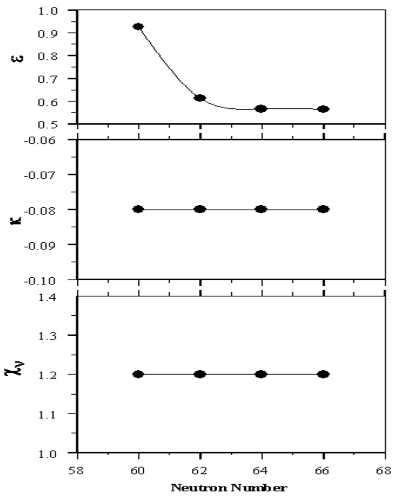

Figure 1. The parameters used in Hamiltonian for IBM-2 calculations for Xe.

The energy level fits with IBM-1 and IBM-2 parameters are shown in Table 3 along with experimental levels of [41].

Table 3. The energy level with IBM-1 and IBM-2 parameters with experimental levels of [41] $^{114\text{-}120}$Xe

N	GS Band					Quasi β – Band			Quasi γ – Band			
	2^+	4^+	6^+	8^+	10^+	0_2	2_3	4_3	2_2	3_1	4_2	
60	0.709	1.459	2.249	3.078	3.944	1.409	2.177	2.976	1.469	2.258	2.260	IBM - 1
62	0.400	0.864	1.390	1.974	2.610	0.816	1.303	1.834	0.871	1.368	1.387	IBM - 1
64	0.338	0.730	1.174	1.669	2.203	0.740	1.184	1.665	0.783	1.228	1.235	IBM - 1
66	0.331	0.735	1.206	1.752	2.346	0.731	1.186	1.704	0.784	1.231	1.254	IBM - 1
60	0.706	1.481	2.318	3.212	4.160	1.612	2.480	3.234	1.487	2.330	2.327	IBM - 2
62	0.398	0.914	1.540	2.273	3.109	1.031	1.631	2.161	0.884	1.476	1.493	IBM - 2
64	0.344	0.807	1.382	2.066	2.854	0.928	1.456	1.853	0.749	1.259	1.291	IBM - 2
66	0.332	0.792	1.373	2.074	2.886	0.903	1.421	1.813	0.722	1.222	1.263	IBM - 2
60	0.449	1.068	1.786	2.478	-	-	-	-	1.147	-	-	Exp
62	0.393	0.917	1.532	2.210	2.961	-	1.321	1.838	1.015	1.474	1.557	Exp
64	0.337	0.810	1.396	2.073	2.816	0.830	1.228	1.730	0.928	1.366	1.441	Exp
66	0.322	0.795	1.397	2.098	2.872	0.908	1.274	1.711	0.875	1.271	1.401	Exp

During the calculation PHINT [49] and NP-BOS [50] codes were used and as it can be seen from Figure 2, 3 and 4, the agreement between experiment and theory is quite good, reproduced well. The Figure 2 is also including the calculated IBM-1 and IBM-2 ground state band ratios $R_{4/2}=E(4^+_1)/E(2^+_1)$, $R_{6/2}=E(6^+_1)/E(2^+_1)$, $R_{8/2}=E(8^+_1)/E(2^+_1)$ and $R_{10/2}=E(10^+_1)/E(2^+_1)$ along with the experimental data.

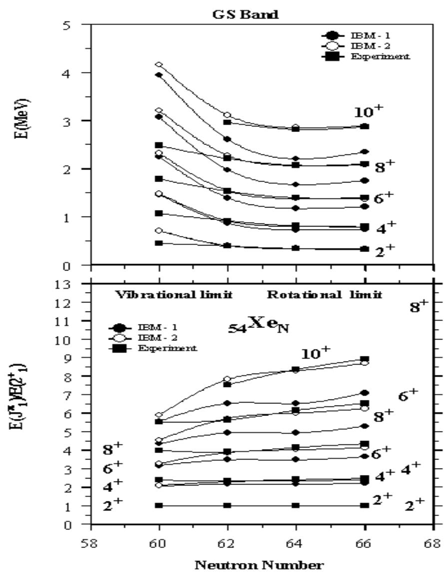

Figure 2. Results of the calculated energies of ground-state band for $^{114\text{-}120}$Xe isotopes.

The experimental values were taken from [41]. The energy ratio $E(J_i)/E(2_1)$ for the J_i= 4_1, 6_1, 8_1 and 10_1 levels for the doubly even Xe isotopes with both the vibrational and rotational limits for this ratio are given in the second part. Those limits are shown on the extreme left and extreme right of the figure respectively.

The Figure 3 and 4 are showing some calculated and experimental energies of the quasi-beta and quasi-gamma bands for $^{114\text{-}120}$Xe nuclei.

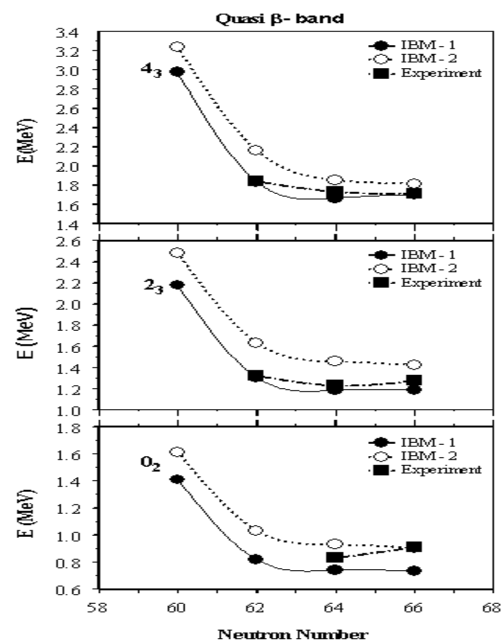

Figure 3. Results of the calculated energies of quasi beta band for $^{114–120}$Xe isotopes. The experimental values were taken from [41].

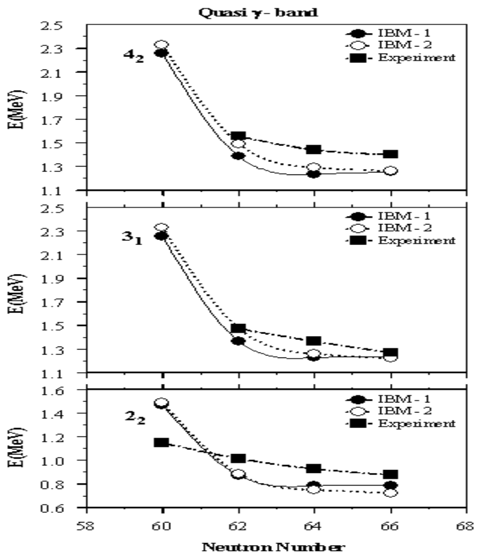

Figure 4. Results of the calculated energies of quasi gamma band for $^{114-120}$Xe isotopes. The experimental values were taken from [41].

Table 4 contains the collective quantities of $R_{2,0,\beta,g}$, $R_{4,2,\beta,g}$, $R_{4,2,\gamma,g}$, described [51],

$$R_{2,0,\beta,g}=\frac{E(2^+_\beta)-E(0^+_\beta)}{E(2^+_1)},\quad R_{4,2,\beta,g}=\frac{E(4^+_\beta)-E(2^+_\beta)}{E(4^+_1)-E(2^+_1)},\quad R_{4,2,\gamma,g}=\frac{E(4^+_\gamma)-E(2^+_\gamma)}{E(4^+_1)-E(2^+_1)} \qquad (5)$$

These collective quantities include the bandheads of the β_1 and γ_1 bands; $E(0^+_\beta)$ and $E(2^+_\gamma)$, which are normalized to $E(2^+_1)$; the spacing within the β_1 band relative to these of the ground state band and the spacing within the γ_1 and relative to that of the ground state band.

Table 4. Comparing theoretical $R_{2,0,\beta,g}$, $R_{4,2,\beta,g}$, $R_{4,2,\gamma,g}$ predictions of IBM-1 and IBM-2 with the experimental data for $^{114-120}Xe$. The band heads of β_1 and γ_1 bands normalized to $E(2^+_1)$ and the experimental values were taken from ref. [41].

N	$R_{2,0,\beta,g}$			$R_{4,2,\beta,g}$			$R_{4,2,,\gamma,g}$		
	IBM-1	IBM-2	Exp	IBM-1	IBM-2	Exp	IBM-1	IBM-2	Exp
60	1.08	1.22	-	1.06	0.97	-	1.05	1.08	1.13
62	1.21	1.50	-	1.14	1.02	0.98	1.11	1.18	1.03
64	1.31	1.53	1.18	0.85	0.85	0.45	1.15	1.17	1.06
66	1.37	1.56	1.13	0.85	0.85	0.92	1.16	1.17	1.11

In this work, the $^{114–120}$Xe nuclei were investigated to provide more detail on the neutron-rich isotopes. The results of the work indicate that the interacting boson model can reproduce a considerable quantity of experimental data and give useful indications where data are in lack. So, one observes the transitions between the three limit symmetries of the model, corresponding to different nuclear shapes and the collective levels are reasonably described. Energy values are better reproduced by the calculation for all Xe isotopes along N = 60–66. The set of parameters used in the calculation of Xe isotopes is only one approximation that has been carried out so far. Here, the gamma-soft rotor features exist in Xe, but with a dominancy of vibrational character. Moreover, it can be said that the presented models are applicable to the nuclei close to axial symmetry.

4. CONCLUSION

We have determined the energies of some members of ground state, quasi beta and quasi gamma bands for ^{114,116,118,120}Xe nuclei within the framework of the Interacting Boson Model. The elegance of figure 2, 3 and 4 suggests a satisfactory agreement between the presented IBM-1 and IBM-2 results, and experimental data for the ground state, quasi beta and quasi gamma band members of ^{114,116,118,120}Xe isotopes. Some of the energy values that are still not known so far are stated. Also, the validity of the presented parameters in IBM formulations was investigated and it was seen that they are the best approximation which has been carried out so far. It is also concluded that the presented results in this work confirms the adequacy of the approximation in this model for ^{114,116,118,120}Xe.

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