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IBM-1 Calculations on the Even-Even $^{180-184}W$ and $^{116-120}Xe$ Isotopes Using Interacting Boson Model (IBM)

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ABSTRACT

The $^{180-184}W$ and $^{116-120}Xe$ isotopes in O(6)-SU(3) transition region has been investigated. For these nuclei, the energy levels, B(E2) transition probabilities are calculated within framework of the Interacting Boson Model (IBM-1). It has been found that the theoretically estimate B(E2) in our calculations in this study are in a good agreement to published transition probabilities which obtained with experimental values. Our B(E2) decrease as the mass number increases and the attestations refer to these isotopes belong to the rotational limit SU(3).

Key words: Energy levels, transition probabilities, interacting boson model

INTRODUCTION

The Interacting Boson Model (IBM), developed by Arima and Iachello (1987) has been rather successful in describing the collective properties of several medium and heavy mass nuclei (Mittal and Devi, 2009). This model is based on the shell model of Jensen and Mayer and in addition has properties similar and in many cases identical to collective model of Boher and Mottelson (Sun *et al.*, 1998). In the simplest version of the IBM, is to assume that low lying collective states in even-even nuclei can be described by a system of interacting s-bosons and d-bosons carrying angular momentum 0 and 2, respectively (Ameer and Al-Shimmary, 2011; Zerguine *et al.*, 2008; Van Isacker, 2008).

The interacting boson model is used as a method of solution and the new different parameters of IBM-1 and IBM-2 are used to describe the various symmetries involve in collective structures (Mittal and Devi, 2009; Turkan and Maras, 2011).

The even-mass tungsten (Navratil *et al.*, 1996) tellurium (Kucukbursa *et al.*, 2005) isotopes have been extensively investigated both theoretically and experimentally in recent years with special emphasis on interpreting experimental data via collective models. Energy levels, electric quadrupole moments, B(E2) values of $^{122-128}Te$ isotopes have been studied within the framework of the semi-microscopic model (Lopac, 1970), the two-proton core coupling model (Degrieck and Berghe, 1974), dynamic deformation model (Subber *et al.*, 1987) and the interacting boson model-2 (Kucukbursa and Yoruk, 1999).

B(E2) values of $^{180-190}W$ isotopes have been studied within the framework of the interacting boson model IBM-1 (Ameer and Al-Shimmary, 2011), it is shown that there is a good agreement between the results found and especially with the experimental ones.

Our aim in this study is to investigate $^{180-184}W$ and $^{116-120}Xe$ isotopes in the transitional region between vibrational and near rotational limits of interacting and calculate the energy levels and B(E2) transition probabilities within framework of the Interacting Boson Model (IBM-1).

METHODOLOGY

Interacting boson model: Interacting Boson Model (IBM-1) has been used in this study. In this section we give a brief description of the IBM the interacting boson model of Arima and Iachello (1987) which has become widely accepted as a tractable theoretical scheme of correlating, describing and predicting low-energy collective properties of complex nuclei (Ameer and Al-Shimmary, 2011). The building blocks of the IBM are s and d-bosons with angular momenta l = 0 and l = 2. A nucleus is characterized by a constant total number of bosons N which equals half the number of valence nucleons (particles or holes whichever is smaller). In this study no distinction is made between neutron and proton bosons, an approximation which is known as IBM-1 (Sorgunlu and Van Isacker, 2008). The model has an inherent group structure, associated with it. In terms of s- and d-boson operators the most general IBM Hamiltonian can be expressed as (Kucukbursa *et al.*, 2005):

$$H = \varepsilon_s s^\dagger s + \varepsilon_d (d^\dagger . d) + \sum_j c_j [(d^\dagger d^\dagger)^{(j)} . (dd)^{(j)}] + 1/2 v_0 [d^\dagger d^\dagger]_0^{(0)} s^2 + (s^\dagger)^2 (dd)_0^{(0)}] + \sqrt{1/2 v_2}\, [[d^\dagger d^\dagger)^{(2)} ds]_0^{(0)} + [s^\dagger d^\dagger (dd)^{(2)}]_0^{(0)} \\ + 1/2 u_0 (s^\dagger)^2 s^2 + 1\sqrt{5 u_2}\, s^\dagger s (d^\dagger . d) \tag{1}$$

This Hamiltonian contains two (one-body) term, (ε_s and ε_d) and seven (two-body) interactions (c_j (J = 0, 2, 4), v_j (J = 0, 2), u_j (J = 0, 2)), where ε_s and ε_d are the single-boson energies and c_j, v_j, u_j describe the two-boson interactions. However, it turn out that for fixed boson number N, only one of the one-body terms and five of the two-body terms are independent, as it can be seen by noting $N = n_s + n_d$.

Hamiltonian equation can be rewritten in terms of the Casimir operators of U(6) group. In that case, one says that the Hamiltonian H has a dynamical symmetry. These symmetries are called SU(5) vibrational, SU(3) rotational and O(6) γ-unstable.

However, it is more common to write the Hamiltonian of the IBM-1 as a multipole expansion, grouped into different boson-boson interactions (Eq. 1) (Turkan and Maras, 2011):

$$H = \varepsilon_d \eta_d + kQ.Q + kL.L + kp.p + q_3 T_3.T_3 + q_4 T_4.T_4 \tag{2}$$

The operators are defined by the following Eq. 3-7:

$$Q.Q = \sqrt{5}\left[\left\{\left(s^+ \tilde{d} + d^+ s\right)^{(2)} - \frac{\sqrt{7}}{2}\left(d^+ \tilde{d}\right)^{(2)}\right\} . \left\{\left(s^+ \tilde{d} + \tilde{d} s\right)^{(2)} - \frac{\sqrt{7}}{2}\left(d^+ \tilde{d}\right)^{(2)}\right\}\right]_0^{(0)} \tag{3}$$

$$L.L = -10\sqrt{3}\left[\left(d^+ \breve{d}\right)^{(1)} . \left(d^+ \breve{d}\right)^{(1)}\right]_0^{(0)} \tag{4}$$

$$P.P = \left[\left\{\left(s^+ s^+\right)_0^{(0)} - \sqrt{5}\left(d^+ d^+\right)_0^{(0)}\right\} . \left\{\left(ss\right)_0^{(0)} - \sqrt{5}\left(\tilde{d}\, \tilde{d}\right)_0^{(0)}\right\}\right]_0^{(0)} \tag{5}$$

$$T_3.T_3 = -\sqrt{7}\left[\left(d^+ \tilde{d}\right)^{(2)} . \left(d^+ \tilde{d}\right)^{(2)}\right]_0^{(0)},\ T_4.T_4 = -\sqrt{7}\left[\left(d^+ \tilde{d}\right)^{(2)} . \left(d^+ \tilde{d}\right)^{(2)}\right]_0^{(0)} \tag{6}$$

$$\eta_d = d^+ \tilde{d} \tag{7}$$

The E2 transition operator must be a Hermitian tensor of rank two and therefore the number of bosons must be conserved. Since with these constraints there are two operators possible in the lowest order, the general E2 operator can be written as (Kucukbursa *et al.*, 2005; Casten and Warner, 1988):

$$\hat{T}_{\mu}^{(E_2)} = \alpha_2 \left[d^{+} x \tilde{s} + \hat{s}^{+} x \breve{d} \right]_{\mu}^{(2)} + \beta_2 \left[\hat{d}^{+} x \breve{d} \right]_{\mu}^{(2)} \tag{8}$$

where, α_2 plays the role of the effective boson charge and:

$$\beta_2 = -\frac{\sqrt{7}}{2\alpha_2} \tag{9}$$

The $B(E_2)$ strength for the E_2 transitions is given by:

$$B(E2; L_i \rightarrow L_f) = 1/(2L_i+1)^{1/2}$$

In this study an application of the IBM is discussed, namely the use of higher order interactions between the d bosons and its relation to triaxiality. First, a simplified IBM Hamiltonian with up to two-body interactions is described which has been used in the systematic analysis of the collective properties of many nuclei. Another application outlines a method where by the full IBM Hamiltonian is used to obtain a simultaneous description of the binding energies and excitation spectra of a large number of nuclei in a single major shell. These numbers of parameters are rather high for practical applications and simplifications must be sought on the basis of physical, empirical or symmetry arguments.

RESULTS AND DISCUSSION

The present study attempts a unitary IBM-1 treatment of positive parity states in the even-even tungsten isotopes 180, 182, 184 and xenon isotopes 116, 118, 120 core nucleus. IBM-1 is a powerful tool for studying the structure of low-lying excited states of even-even nuclei (Abul-Magd *et al.*, 2010).

The examination of the experimental energy levels for the nuclei $^{180-184}W$ and $^{116-120}Xe$ shows that they lie in the transitional region SU(3)→O(6), therefore the Hamiltonian of the transition region SU(3)→O(6) has been employed in the calculation by using the program PRINT written by (Sorgunlu and Van Isacker, 2008).

The analysis and the main results for energy levels and B(E2) transition probabilities agree very well with experiment. In general, good agreement was obtained when compared with experiment. The boson-boson interaction parameters were fixed by the calculations on the boson core nuclei. The results indicate that the energy spectra of all the different quasi bands of the tungsten and xenon isotopes can be reproduced quite well. It is noticed, however, that the results of B(E2) calculations for even-even nuclei were in better agreement with the existing experimental data.

The best fit values for the Hamiltonian parameters for even-even tungsten isotopes and xenon isotopes are given in Table 1, the calculated energy values which are compared with the experimental data (Ameer and Al-Shimmary, 2011; Turkan and Maras, 2011) are given in Fig. 1a-c, 2a-c for 180, 182, 184 W isotopes and 116, 118, 120 Xe isotopes, respectively. The

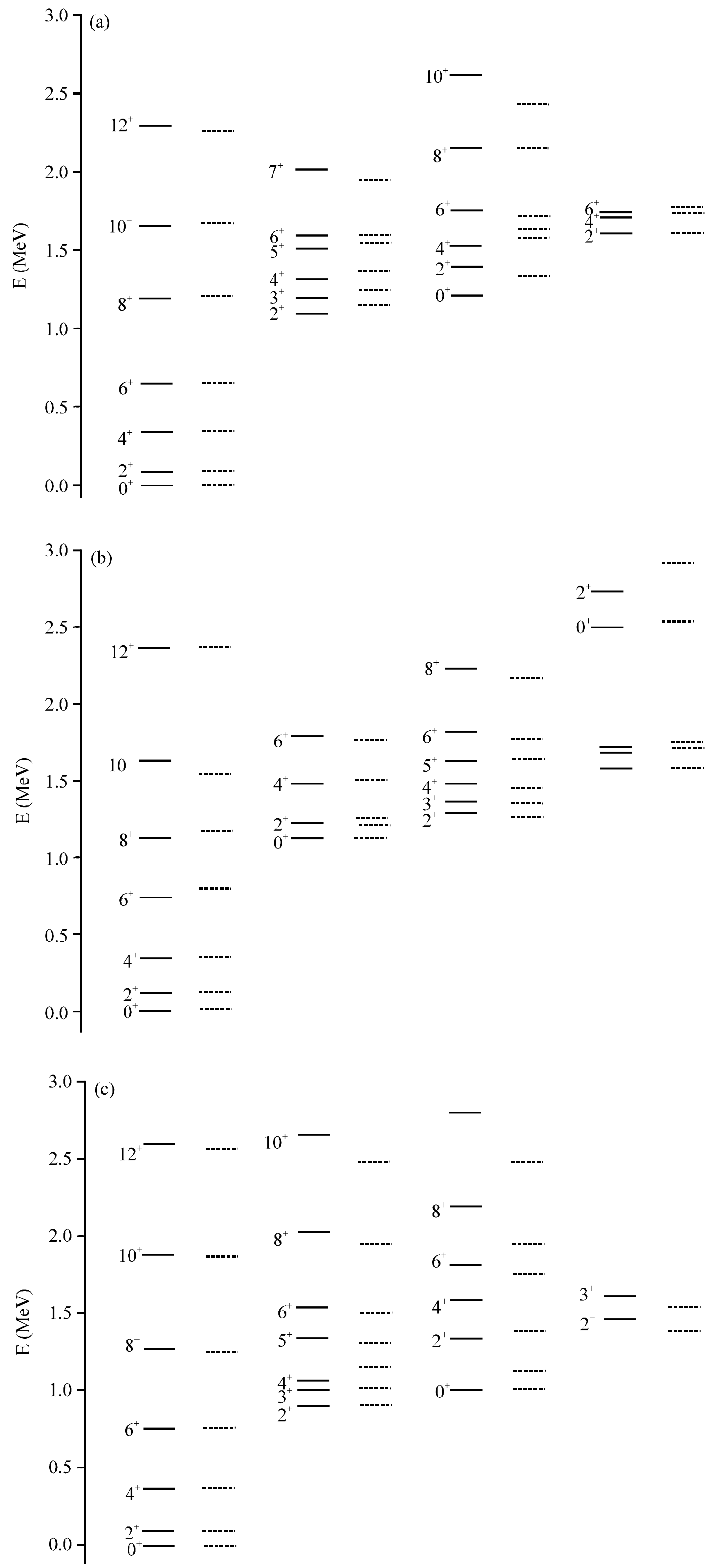

Fig. 1(a-c): Experimental and theoretical energy levels for (a) ^{180}W, (b) ^{182}W and (c) ^{184}W

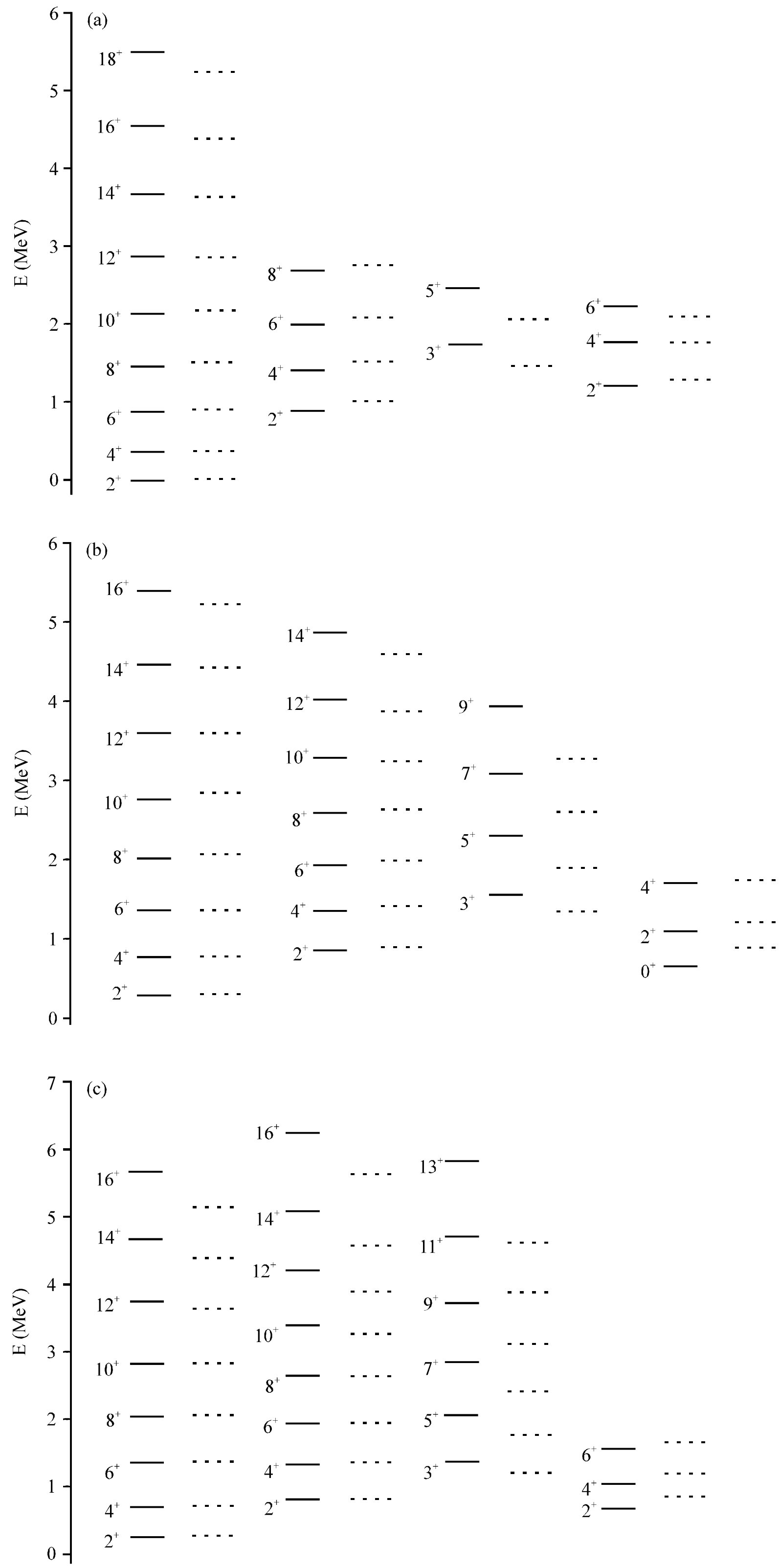

Fig. 2(a-c): Experimental and theoretical energy levels for (a) ^{116}Xe, (b) ^{118}Xe and (c) ^{120}Xe

Table 1: Hamiltonian parameters

A	EPS	P.P	L.L	Q.Q	$T_3.T_3$	$T_4.T_4$
	(MeV)					
^{182}W	0.00000	0.04968	0.01034	-0.01242	0.0000	0.0000
^{184}W	0.00000	0.060348	0.012562	-0.01509	0.0000	0.0000
^{186}W	0.00000	0.040401	0.012514	-0.00859	0.0000	0.0000
^{116}Xe	0.12350	0.01425	0.00855	-0.0057	0.00104	-0.00741
^{118}Xe	0.11160	0.016275	0.00930	-0.00558	0.001023	-0.00725
^{120}Xe	0.09900	0.018000	0.01800	-0.0054	0.00099	-0.00702

Table 2: Experimental values of B(E2) and the coefficients (E2SD, E2DD) for $^{180-184}$W and $^{116-120}$Xe isotopes

A	B $(E2;2^+_1\rightarrow 0^+_1)$ e^2b^2	E2SD (e b)	E2DD (e b)
^{182}W	0.840	0.100271	-0.296603
^{184}W	0.756	0.100451	-0.297138
^{186}W	0.700	0.103226	-0.305346
^{116}Xe	1.628	0.1943	-0.5748
^{118}Xe	1.61	02139	-0.6328
^{120}Xe	1.5316	0.22585	-0.6681

calculated values in this study show that the transitions connect the levels with the same parity and the E2 transitions are predominant. It can be seen from Table 1 and 2 for tungsten and xenon isotopes, respectively that theoretical B(E2) values agree with the experimental data within the indicated errors. A satisfactory comparison with the experiments is quite difficult due to the large errors in the experimental values. Moreover, the theoretical B(E2) values for that transition seem to be systematically too small. This can be explained by the fact that many small components of the initial and final wave functions contribute coherently to the value of this reduced E2 transition probability. Since these small components are not stable enough against small changes in the model parameters, a quantitative comparison with the experimental data is not possible. Though the observed B(E2) values for the odd xenon isotopes are very few.

CONCLUSION

In the present study we studied systematically the lower and higher state of lower and higher bands of the B(E2) transition probabilities for even-even $^{180-184}$W and $^{116-120}$Xe isotopes which lies in the transitional region (6)-SU(3) of IBM-1. Good agreement have been obtained in comparison with the experimental data and our model used in this study with the best fitted parameters proves that the nuclei ^{118}Xe and ^{120}Xe have high deformation and tend to be near O(6) limit than to SU(3) limit and the B(E2) transition probabilities decrease as the mass number increase.

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