YRAST STATES AND ELECTROMAGNETIC REDUCED TRANSITION PROPERTIES OF ^{122}Te BY MEANS OF INTERACTING BOSON MODEL-1

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In this paper, the yrast states and the electric reduced transition probabilities $B(E2)\downarrow$ from gamma transition 8^+ to 6^+, 6^+ to 4^+, 4^+ to 2^+ and 2^+ to 0^+ states of neutron rich ^{122}Te nucleus in the frame work of Interacting Boson Model-I (IBM-I) have carried out. The calculated results have been compared with the available experimental values. The ratio of the excitation energies of first 4^+ and 2^+ excited states ($R_{4/2}$), have also been calculated for this nucleus. An acceptable degree of agreement between the predictions of IBM-I model and experiment is achieved. Moreover, as a measure to quantify evolution, we studied the transition rate $R = B(E2: L^+ \rightarrow (L-2)^+)/B(E2: 2^+ \rightarrow 0^+)$ of some of the low-lying quadrupole collective states in comparison to the available experimental data. The IBM-I formula for energy levels and the reduced transition probabilities $B(E2)$ have been analytically deduced in the $U(5)$ limit for a few yrast states transitions in ^{122}Te isotope.

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1. INTRODUCTION

The interacting boson model-I (IBM-I) is a valuable interactive model developed by Iachello and Arima [1,2]. It has been successful in describing the collective nuclear structure by prediction of low-lying states and description of electromagnetic transition rates in the medium mass nuclei. IBM defines six-dimensional space described by in terms of the unitary group, $U(6)$. Different reductions of $U(6)$ give three dynamical symmetry limits known as harmonic oscillator, deformed rotator and asymmetric deformed rotor which are labeled by $U(5)$, $SU(3)$ and $O(6)$ respectively [3,4].

Even-even tellurium isotopes are part of an interesting region beyond the closed proton shell at $Z = 50$, while the number of neutrons in the open shell are larger, which are commonly considered to exhibit vibration-like properties [5]. Yrast states up to $I^\pi = 8^+$ in $Z = 2$ isotones were found by $\pi h^{+2}_{11/2}$ configurations for $Z = 50$ closed shell. It is known that low-lying collective quadrupole $E2$ excitations occur in even-even nuclei $Z = 52$ and $N = 70$, which have been studied both theoretically and experimentally. Reorientation effect measurements in ^{122}Te nucleus were investigated by Bechara et al. [6]. and Barrette et al. [7]. Energy levels, electric quadrupole moments of ^{122}Te nucleus have been studied within the framework of the semi microscopic model [8], the two-proton core coupling model [9] and dynamic deformation model [10].

There are number of theoretical works discussing intruder configuration and configuration mixing by means of IBM-I around the shell closure $Z = 50$. For instance, empirical spectroscopic study within the configuration mixing calculation in IBM [11,12]. IBM configuration mixing model in strong connection with shell model [13,14], conventional collective Hamiltonian approach [15,16] and one starting from self-consistent mean-field calculation with microscopic energy density functional [17]. Recently we have studied the evolution properties of the yrast states for even-even $^{100-110}Pd$ isotopes [18]. The electromagnetic reduced transition probabilities of

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even-even $^{104-112}Cd$ isotopes were studied by Abdullah et al [19]. The analytic IBM-I calculation of $B(E2)$ values of even-even $^{102-106}Pd$ have confirmed $U(5)$ character [20].

The basic property of a nucleus is the probability of electric quadrupole ($E2$) transitions between its low-lying states. In even-even nuclei, the reduced $E2$ probability $B(E2;\, 0+_1 \to 2^+_1)$ from 0^+ ground state to the first-excited 2^+ state is especially important, and for a deformed nucleus this probability (denoted here by $B(E2\uparrow)$) depends on the magnitude of the intrinsic quadrupole moment (quadrupole moment of the intrinsic state of the nucleus) and, hence, on deformation [21]. The problem of the research is to investigate ^{122}Te nucleus in $U(5)$ limit and calculate the energy levels and the transition rates of the yrast state band up to 8^+ to 6^+ level through $E2$ transition strengths and back-bending phenomena.

2. MATERIAL AND METHODS

2.1. Yrast-state energy levels

The Hamiltonian of the interacting bosons in IBM-1 [22].

$$H = \sum_{i=1}^{N} \varepsilon_i + \sum_{i<j}^{N} V_{ij}\,, \tag{1}$$

where ε_i is the intrinsic boson energy and V_{ij} is the interaction between bosons i and j.

In the multi-pole form the Hamiltonian [23].

$$H = \varepsilon n_d + a_0 PP + a_1 LL + a_2 QQ + a_3 T_3 T_3 + a_4 T_4 T_4\,. \tag{2}$$

Here, a_0, a_1, a_2, a_3 and a_4 are the strength of pairing, angular momentum and multi-pole terms. The Hamiltonian as given in Eq.(2) tends to reduce to three limits, the vibration $U(5)$, γ-soft $O(6)$ and the rotational $SU(3)$ nuclei, starting with the unitary group $U(6)$ and finishing with group $O(2)$ [23]. In $U(5)$ limit, the effective parameter is ε, in the γ-soft limit, $O(6)$, the effective parameter is the pairing a_0, and in the $SU(3)$ limit, the effective parameter is the quad pole a_2. The eigen-values for the three limits given as [23]

$$U(5):\ E(n_d,\, \nu,\, L) = \varepsilon n_d + K_1 n_d(n_d+4) + K_4\nu(\nu+3) + K_5 L(L+1)\,, \tag{3}$$

$$O(6):\ E(\sigma,\, \tau,\, L) = K_3[L(N+4) - \sigma(\sigma+4)] + K_4\tau(\tau+3) + K_5 L(L+1)\,, \tag{4}$$

$$SU(3):\ E(\lambda,\, \mu,\, L) = K_2[\lambda^2 + \mu^2 + 3(\lambda+\mu) + \lambda\mu] + K_5 L(L+1)\,. \tag{5}$$

Here, K_1, K_2, K_3, K_4 and K_5 are other forms of strength parameters. Many nuclei have a transition property between two or three of the above limits and their eigen-values for the yrast-line [23].

2.2. Reduced transition probabilities B(E2)

The low-lying levels of even-even nuclei ($L_i = 2, 4, 6, 8, ...$) usually decay by one $E2$ transition to the lower-lying yrast level with $L_f = L_i - 2$. The reduced transition probabilities in IBM-I are given for the anharmonic vibration limit $U(5)$ [22].

$$B(E2;\, L+2 \to L)\downarrow = \frac{1}{4}\alpha_2^2 (L+2)(2N-L) = \frac{1}{4}\frac{(L+2)(2N-L)}{N} B(E2;\, 2\to 0)\,, \tag{6}$$

where L is the state that nucleus transion to and N is the boson number, which is equal to half the number of valence nucleons (proton and neutrons). From the given experimental value $B(E2)$ of transition ($2^+ \to 0^+$), one can calculate value of the parameter α_2^2 for each isotope, where α_2^2 indicates the square of effective charge. This value is used to calculate the transition 8^+ to 6^+, 6^+ to 4^+, 4^+ to 2^+ and 2^+ to 0^+.

3. RESULTS AND DISCUSSION

The ^{122}Te nucleus has an atomic number $Z = 52$ and neutron number $N = 70$. It has 14 valence nucleons or 7 bosons relative to the shell closures $Z = 50$ and $N = 82$. A boson number represents the pair of valence nucleons and boson number is counted as the number of collective pairs of valence nucleons. A simple correlation exists between the nuclei showing identical spectra and their valence proton number (N_p) and neutron number (N_n). The number of valance proton N_p and neutron N_n has a total $N = (N_p + N_n)/2 = n_\pi + n_\nu$ bosons ^{132}Sn doubly-magic nucleus is taken as an inert core to find boson number. Boson numbers and the calculated parameters of different levels for ^{122}Te nucleus in IBM-I are presented in Table 1. All parameters are given in units of keV.

The energy of yrast states band (i.e. 0^+, 2^+, 4^+, 6^+, 8^+) for doubly even isotopes ^{122}Te has been calculated by using Eq.(3) in model. For the yrast-state bands only the levels up to spin 8^+ were considered in the calculation since above this spin value the yrast bands exhibit a backbend phenomenon. Suitable free parameters have been determined to find the close excitation-energy of all positive parity levels (2^+, 4^+, 6^+, 8^+) for which a good indication of the spin value exists [24]. Table 1 shows the values of these parameters that have been used to calculate the energy of the yrast- states for the isotopes $Z = 52$ and $N = 70$ under this study.

Table 1. *Bosons number and the calculated parameters for different levels in IBM-1 for ^{122}Te nucleus.*

Nucleus	N	States	Limits	ε keV	K_1 keV	K_4 keV	K_5 keV
^{122}Te	7	2-8	$U(5)$	451.183	39.386	-24.092	2.058

Table 2. *The calculated and experimental [24] yrast level and percentage of error for ^{122}Te.*

I^π	$E_{exp}(keV)$	$E_{cal}(keV)$	$\Delta\%$
2^+	564.09	564.09	0.00
4^+	1181.25	1175.2	0.51
6^+	1751.32	1833.4	4.69
8^+	2669.67	2538.6	4.91

The energy levels that fit with IBM-1 are presented in Table 2 and they are compared with the experimental levels [24]. The agreement between calculated and experimental values is excellent and reproduced well. The values of the first excited state $E2_1^+$ and the ratio $R = E4_1^+/E2_1^+$ show that ^{122}Te isotope is vibration nucleus.

Table 3 presents reduced transition probabilities $B(E2)\downarrow$ for the yrast state band from 8^+ to 6^+, 6^+ to 4^+, 4^+ to 2^+, and 2^+ to 0^+ of even-even ^{122}Te isotope. Using known experimental $B(E2)\downarrow$ from $2_1^+ \to 0_1^+$ transition, the reduced transition probabilities of $4_1^+ \to 2_1^+$, $6_1^+ \to 4_1^+$ and $8_1^+ \to 6_1^+$ transitions of even-even ^{122}Te isotope are calculated by using IBM-1 and presented in Table 3. The calculated results are also compared with the previous experimental results [24].

Table 3. *Reduced transition probability $B(E2)\downarrow$ of even-even ^{122}Te nucleus [24].*

Nucl	α_2^2 W.u.	Transition Level	$B(E2)$ W.u.	$B(E2)_{IBM-1}$ W.u.
^{122}Te	5.27 ± 0.04	$2_1^+ \to 0_1^+$	36.92 ± 0.25	36.92 ± 0.25
		$4_1^+ \to 2_1^+$		63.24 ± 0.48
		$6_1^+ \to 4_1^+$		79.05 ± 0.60
		$8_1^+ \to 6_1^+$	61 ± 21	84.32 ± 0.64

3.1. $R_{4/2}$ classifications

It is known that collective dynamics of energies in even-even nuclei are grouped into classes, within each class the ratio of excitation energies of first 4^+ and 2^+ excited states is: spherical vibrator $U(5)$ has $R_{4/2} = 2.00$, -unstable rotor $O(6)$ should have $R_{4/2} = 2.5$ and an axially symmetric rotor $SU(3)$ should have $R_{4/2} = 3.33$. We have examined $U(5)$ symmetry as $R_{4/2} = 2.09$ in ^{122}Te.

3.2. Reduced transition probabilities $B(E2)$

The value of the effective charge α_2 of IBM-I have been determined by normalizing the experimental data $B(E2;\, 2_1^+ \to 0_1^+)$of ^{122}Te isotope using Eq.(6). From the given experimental value of transitions $(2_1^+ \to 0_1^+)$, we have calculated the value of the parameter α_2^2 for ^{122}Te isotope and used this value to calculate the transitions from $4_1^+ \to 2_1^+$, $6_1^+ \to 4_1^+$ and $8_1^+ \to 6_1^+$. The values of the fitted parameter α_2^2 remark the meaning of the square of effective boson charge and presented in Table 3. The theoretical values of $B(E2)$ in W.u. using IBM-I are increased with the transition levels. The results of present work are compared with the previous experimental values [24] and are in good agreement within experimental error. Another condition of $U(5)$ limit [23] would be confirmed by the expression for $B(E2)$ ratios as $B(E2;\, 4_1 \to 2_1)/B(E2;\, 2_1 \to 0_1) = 2(N-1)/N < 2$. In IBM-I the ratio of $B(E2;\, 4_1 \to 2_1)/B(E2;\, 2_1 \to 0_1)$ in ^{122}Te is 1.71 and $2(N-1)/N$ value of ^{122}Te is 1.71. Therefore, the present calculations are firmly in the $U(5)$ limit and therefore a good agreement between the calculated values and the experimental ones indicated that ^{122}Te isotope obey to this limit. Even-even ^{122}Te nucleus is nicely reproduced by the experimental data, and their fits are satisfactory.

Fig.1 shows ratio $R = E(L_1^+)/E(2_1^+)$ values versus yrast state spin momentum (L) of ^{122}Te isotope by IBM-I and experiment results [24].

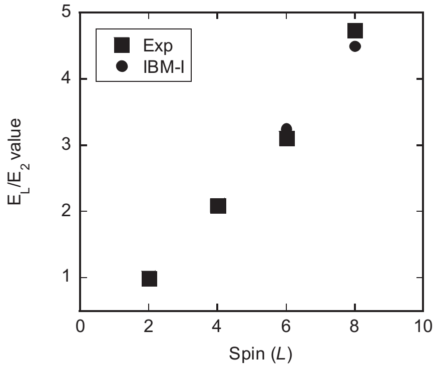

Fig.1. *Plot of ratio $R = E(L_1^+)/E(2_1^+)$ values versus yrast state spin momentum (L) of ^{122}Te isotope by IBM-I and experiment results [24]. The ratio $R = E(L_1^+)/E(2_1^+)$ in yrast state bands are normalized to $E(2_1^+)$*

The ratio $R = E(L_1^+)/E(2_1^+)$ in yrast state band are normalized to $E(2_1^+)$. As a measure to quantity evolution, it is shown that results of R values increase with increasing the high spin states. We have compared the ratio $R = B(E2 : L^+ \to (L-2)^+)/B(E2 : 2^+ \to 0^+)$ of IBM-I and previous available experimental values in the yrast state bands (normalized to the $B(E2 : 2^+ \to 0^+)$ as a function of angular momentum L and are shown in Fig.2.

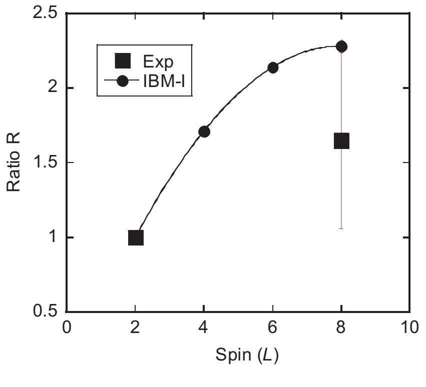

Fig.2. *R values of ^{122}Te isotope using IBM-I and experiment shown as a function of spin momentum L [24]. The ratio $R = B(E2 : L_+ \to (L-2)^+)/B(E2 : 2^+ \to 0^+)$ in the yrast state band (normalized to the $B(E2 : 2^+ \to 0^+)$)*

It is shown that the value of R is increased with increasing the high spin states. We have found that the calculated values are in good agreement with the previous available experimental results [24].

3.3. Comparative studies of ^{122}Te and ^{118}Cd nuclei

The neutron-rich ^{132}Sn nucleus is known to the properties of doubly closed shells and its core excitation can provide valuation information on the nuclear structure. ^{122}Te and ^{118}Cd nuclei consist of $Z = 52$, $N = 70$ and $Z = 48$, $N = 70$ respectively. Therefore, 2 particles and 2 hole belongs to ^{122}Te and ^{118}Cd nuclei with respect to shell closure $Z = 50$. From a theoretical point of view, the yrast states up to $I^\pi = 8^+$ in $Z = 48$ isotopes can be ascribed to two-hole states $\pi g_{9/2}^{-2}$ for $Z = 50$ closed shell. Recently, we have investigated yrast level and transition strength of even-even ^{118}Cd [25, 26] nucleus by IBM-1 and found that it is a vibrational nucleus which $U(5)$ is symmetry. This investigation is raised the possibilities that a similar situation could exist for ^{122}Te nucleus. The level spacing and transition strengths should be same for ^{122}Te and ^{118}Cd. Fig.3 shows yrast level as a function of spin for ^{122}Te and ^{118}Cd nuclei.

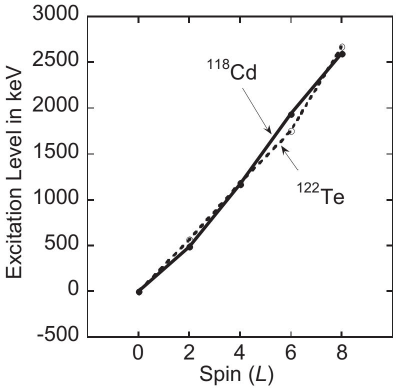

Fig.3. *Yrast level of ^{122}Te and ^{118}Cd nuclei as a function of spin momentum L*

The 2^+, 4^+, 6^+, and 8^+ levels are 560.4, 1161.5, 1776.1 and 2652.8 keV for ^{122}Te nucleus and 487.8, 1164.9, 1935.9 and 2590.9 keV for ^{118}Cd. Therefore yrast levels are almost same except 6^+. This fact suggests that the 6^+ state in ^{122}Te nucleus has a significant admixture of other components. The reduced transition probability $B(E2)\downarrow$ from $2_1^+ \to 0_1^+$, is $36.92 \pm 0.25\, W.u.$ for ^{122}Te and $33 \pm 3\, W.u.$ for ^{118}Cd are consistent to each other.

3.4. Moments of inertia

The moments of inertia are calculated from the following equation:

$$\frac{2\vartheta}{\hbar^2} = \frac{2(2I-1)}{E(I)-E(I-2)} = \frac{4I-2}{E_\gamma}\,.$$

Fig.4 shows the moment of inertia for the yrast states band of ^{122}Te and ^{118}Cd are plotted as function of $I(I+1)$. According to variable moment of inertia (VMI) model this should give a straight line in the plot of $2\vartheta/\hbar^2$ vs $I(I+1)$ in the lowest order. We have investigated first order backbend at 12^+ states in ^{122}Te and 10^+ states in ^{118}Cd.

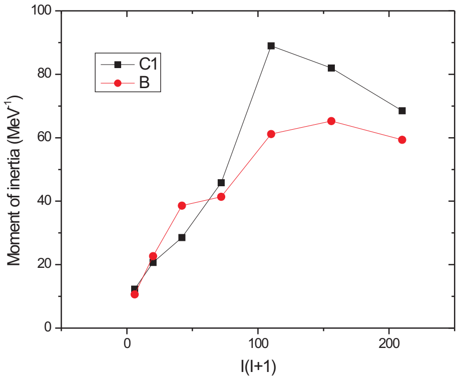

Fig.4. *Moment of inertia as a function of* $I(I+1)$ *of* ^{122}Te *and* ^{118}Cd *nuclei*

4. CONCLUSIONS

In this work, the yrast-state energy band and reduced transition probabilities $B(E2)$ values of even-even ^{122}Te nucleus have been investigated by IBM-I. The results are compared with some previous experimental data [24]. The calculated excitation energies and the experimental ones are in good agreement. The analytical IBM-I calculation of yrast levels and $B(E2)$ values up to 8_1^+ levels of ^{122}Te isotope have been performed in the $U(5)$ character and this approach agree with previous study [27] using another method. The yrast states and $B(E2)$ values of 2 particles in ^{122}Te nucleus and two holes in ^{118}Cd nucleus are similar structure for shell closure $Z=50$. Furthermore, the present results are better than that those ref.[28]. The back-bending phenomena appear clearly in the diagram $2\vartheta/\hbar^2$ vs $I(I+1)$. The results are extremely useful for compiling nuclear data table. Acknowledgements: The authors thanks to king Abdulaziz University.

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YRAST-СОСТОЯНИЯ И ПРИВЕДЕННЫЕ ВЕРОЯТНОСТИ ЭЛЕКТРОМАГНИТНЫХ ПЕРЕХОДОВ ^{122}Te В МОДЕЛИ ВЗАИМОДЕЙСТВУЮЩИХ БОЗОНОВ

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Получены yrast-состояния и приведенные вероятности электрических переходов $B(E2)\downarrow$ от γ-переходов между состояниями 8^+ и 6^+, 6^+ и 4^+, 4^+ и 2^+, а также 2^+ и 0^+ в богатом нейтронами ядре ^{122}Te в рамках модели взаимодействующих бозонов (IBM-I). Результаты расчетов сравнены с наличными экспериментальными величинами. Отношение энергий возбуждения ($R_{4/2}$) первых возбужденных состояний 4^+ и 2^+ для данного ядра были также рассчитаны. Получено удовлетворительное согласие между предсказаниями модели IBM-I и экспериментом. Кроме этого, для оценки процесса мы изучили соотношение переходов $R = B(E2:\ L^+ \to (L-2)^+)/B(E2:\ 2^+ \to 0^+)$ между некоторыми низколежащими квадрупольными коллективными состояниями в сравнении с доступными экспериментальными данными. IBM-I формула для энергетических уровней и приведенных вероятностей переходов $B(E2)$ была получена аналитически в $U(5)$-приближении для нескольких переходов между yrast-состояниями в изотопе ^{122}Te.

YRAST-СТАНИ І ПРИВЕДЕНІ ВІРОГІДНОСТІ ЕЛЕКТРОМАГНІТНИХ ПЕРЕХОДІВ ^{122}Te У МОДЕЛІ ВЗАЄМОДІЮЧИХ БОЗОНІВ

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Отримані yrast-стани і приведені вірогідності електричних переходів $B(E2)\downarrow$ від γ-переходів між станами 8^+ і 6^+, 6^+ і 4^+, 4^+ і 2^+, а також 2^+ і 0^+ у багатому нейтронами ядрі ^{122}Te в рамках моделі взємодіючих бозонів (IBM-I). Наслідки розрахунків порівняні з наявними експериментальними величинами. Відношення енергій збудження ($R_{4/2}$) перших збуджених станів 4^+ и 2^+ для данного ядра були також розраховані. Отримано задовільне узгодження між передбаченнями моделі IBM-I та експериментом. Крім цього, для оцінки процесу ми вивчили співвідношення переходів $R = B(E2:\ L^+ \to (L-2)^+)/B(E2:\ 2^+ \to 0^+)$ між кількома низколежачими квадрупольними колективними станами в порівнянні з відомими експериментальними даними. IBM-I формула для енергетичних рівнів та приведені вірогідності переходів $B(E2)$ булиа отримана аналітично в $U(5)$ наближенні для кількох переходів між yrast-станами в ізотопі ^{122}Te.