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AN IBM(2) INVESTIGATION OF SOME PROPERTIES OF ^{100}Ru NUCLEI

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ABSTRACT

In this study, energy values, B(E2) values and quadrupole moment of ^{100}Ru isotope at the onset of the deformed region were investigated by using the Interacting Boson Model (IBM-2). The results were compared with the experimental and theoretical values and it is determined that they are in good agreement.

I. INTRODUCTION

In recent years, the use of dynamical symmetry Hamiltonians has brought about significant developments in nuclear structure physics. The original SU(5), SU(3) and SO(6) dynamical symmetries of the interacting boson approximation (IBM) model have played an important role in these developments. In this work, a geometrical interpretation of an IBM analysis of ^{100}Ru isotope is given.

II. THEORY

According to Arima et al. [1] IBM Hamiltonian takes different forms depending on the regions (SU(5), SU(3), SO(6)) of the traditional IBA triangle. In the IBA-2 model the neutrons' and protons' degrees of freedom are taken into account explicitly. Thus the Hamiltonian[2] can be written as

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

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

$$n_{d\rho} = d^+ d^\sim , \rho = \pi , \nu$$

$$d^\sim_{\rho m} = (-1)^m d_{\rho -m} \tag{2}$$

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

$$Q_\rho = (s^+_\rho \tilde{d}_\rho + d^+_\rho s_\rho) + \chi_\rho (d^+_\rho \tilde{d}_\rho)$$

$$V_{\rho\rho} = \sum_{L=0,2,4} C_{L\rho} \left((d^+_\rho d^+_\rho)^{(L)} (d^+_\rho \tilde{d}_\rho)^{(L)} \right)^{(0)} ; \rho = \pi , \nu \quad (3)$$

and

$$M_{\pi\nu} ; \sum_{L=1,3} \xi_L (d^+_\nu d^+_\pi)^{(L)} (d_\nu d_\pi)^{(L)}$$

$$+ \xi_2 (s_\nu \tilde{d}_\pi - s_\pi \tilde{d}_\nu)^{(2)} (s^+_\nu d^+_\pi - s^+_\pi d^+_\nu)^{(2)} \quad (4)$$

In this case $M_{\pi\nu}$ affects only the position of the non-fully symmetric states relative to the symmetric ones. Therefore $M_{\pi\nu}$ is often called as the Majorana force[2].

The electric quadrupole (E2) transitions are one of the important factors within the collective nuclear structure. In IBM, the general linear E2 operator is given by

$$T(E2) = \alpha_2 (s^+ d + d^+ s) + \beta_2 [d^+ d]_2$$

$$= \alpha_2 (s^+ d + d^+ s) + \chi [d^+ d]_2 \quad (5)$$

In this form, α_2, β_2 and χ are free parameters. The important physical properties calculated by E2 operator are $B(E2;J\rightarrow J')$ and quadrupole moment $Q(J)$.

$B(E2;J\rightarrow J')$ and $Q(J)$ are given in the following formulation

$$B(E2;J\rightarrow J') = \sum_{mM'} |\langle J'M'|T(E2)_m|JM\rangle|^2$$

$$B(E2;J\rightarrow J') = \frac{1}{2J+1} |(J'||T(E2)||J)|^2 \quad (6)$$

and

$$Q(J) = \sqrt{\frac{16\pi}{5}} \langle JJ|T(E2)_0|JJ\rangle \quad (7)$$

III. CALCULATIONS AND RESULTS

Energies and eigen-vectors for positive and negative parity states can be calculated in the framework of the IBA model[3] by means of a computer program. This program package calculate the energy levels, B(E2) and $Q(2^+)$ values in the formalism of IBM-2.

de Voight et al. [4] explained the multipolarities of the energy levels, transition coefficients, branching and quadrupole/dipole amplitude mixing ratios of ^{100}Ru isotope. But so far, the multipolarities of this isotope have not been determined completely. Moreover, the calculations cover the negative parity states. In the decay scheme of ^{100}Ru the spins of 0^+, 2^+, 4^+ and 6^+ states are calculated to be 0.0, 508.5, 1158.0 and 1926.3 keV. This is the ground state band. The beta band consists of the spins 0^+, 2^+, 4^+ at the calculated levels of 1130.0, 1283.5 and 2104.4 keV. These results are shown in Table 1 together with the previous experimental data.

Table 1. Energy Levels of ^{100}Ru isotope.

Band Structure (K^π)	Spin Parite (J^π)	Calculated Energy Level (keV)	Experiment [5]
Ground state Band	0^+	0.0	0.0
(K^π) = 0^+	2^+	508.5	539.6
	4^+	1158.0	1226.5
	6^+	1926.3	2076.0
Beta Band	0^+	1130.0	1130.0
(K^π) = 0^+	2^+	1283.5	1362
	4^+	2104.4	2062

The B(E2) and $Q(2^+)$ values are also calculated and the results are given in Tables 2-3.

Table 2. Some Calculated B(E2) values for ^{100}Ru.				
J_i^{π}	J_f^{π}	Experiment [8]	This Work	Previous Work (Theoretical)
2_1^+	0_1^+	0.0964	0.1058	0.1022[9] 0.1022[10] 0.1002[6,7]
4_1^+	2_1^+	0.1444	0.1432	0.1456[9] 0.1430[10] 0.144[6,7]
2_1^+	0_2^+			0.0065[10]
2_2^+	0_1^+	0.0041	0.0222	0.0037[9] 0.0015[10] 0.0011[6,7]
2_2^+	2_1^+	0.088	0.0821	0.0910[9] 0.095[10] 0.128[6,7]
0_2^+	2_1^+			0.058[6,7]
2_3^+	0_1^+		0.0003	0.0002[6,7]
2_3^+	0_2^+		0.0460	0.060[6,7]
2_3^+	2_1^+		0.0012	0.0996[6,7]

In Table 3, the calculated quadrupole moment of 2^+ of ^{100}Ru, $Q(2^+)$ value, is compared with some experimental and theoretical results.

Table 3. Calculated and experimental $Q(2^+)$ for ^{100}Ru.		
Experiment	This Work	Others
-0.40 ± 0.12[11] -0.43 ± 0.07[9] -0.13 ± 0.07[12]	-0.42	-0.41[10]

The B(E2) ratio calculated for ^{100}Ru isotope is compared with that of IBM limits given in Table 4.

Table 4. Comparison of some B(E2) ratios between ^{100}Ru and IBM limits.

isotope and the name of region	$\frac{B(E2;2_2^+\to 0_1^+)}{B(E2;2_2^+\to 2_2^+)}$	$\frac{B(E2;2_2^+\to 2_1^+)}{B(E2;2_1^+\to 0_1^+)}$	$\frac{B(E2;3_1^+\to 2_1^+)}{B(E2;3_1^+\to 4_1^+)}$	$\frac{B(E2;4_2^+\to 4_1^+)}{B(E2;4_2^+\to 2_2^+)}$	$\frac{B(E2;4_1^+\to 2_1^+)}{B(E2;2_2^+\to 2_1^+)}$
SU(5) [13]	0.011	1.40	0.06	0.72	1.0
SU(3) [13]	0.70	0.02	2.50	0.03	6.93
O(6) [13]	0.07	0.79	0.12	0.75	1.84
^{100}Ru (This Work)	0.06	0.80	0.08	0.72	1.74

Calculated energy levels are in agreement with experimental ones as shown in Table 1. It is obviously seen from Table 2 that the calculated results are in good agreement with that of other experimental and theoretical work done before. Table 3 also shows a satisfactory agreement among the experimental, theoretical and calculated result for the quadrupole moment. In Table 4, the comparison of some B(E2) ratios of ^{100}Ru with that of SU(3),SU(5) and SO(6) limits show that ^{100}Ru isotope is existing in SU(5)-SO(6) side of the IBM triangle. In other words, ^{100}Ru is far from indicating the properties of the isotopes belonging to deformed region. ^{100}Ru exists around the closed neutron shell (N=50) and shows a triaxial deformation. Especially, $\frac{B(E2;2_2^+\to 2_1^+)}{B(E2;2_1^+\to 0_1^+)}$ ratio of ^{100}Ru in Table 4 has the tendency towards the SU(5) region with an indication of triaxial deformed character.

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