E0 Transition as Another Indicator for Nuclear Shape Transitions and an Application to $^{102-110}$Pd *

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Abstract The E0 transitions in the even-even$^{102-110}$Pd isotopes are studied in the $U(5)-SU(3)$ and the $U(5)-O(6)$ transition in the framework of the interacting boson model respectively. It is found that the structure of the isotopes can be better described by the $U(5)-SU(3)$.

Key words E0 transition, Positive parity low-lying collective state, nuclear deformation

1 Introduction

As is known, it is very important to study the E2 transitions in nuclear structure. However, the E2 transition is not the only way that the nucleus de-excitates from an excited state. There are other ways of de-excitation such as internal-conversion (IC) and internal-pair formation (IP). IC comes into being when the atomic electrons are given electromagnetic energy by the nucleus, so does IP when electromagnetic energy is above 1.02MeV. It is impossible that the E2 transition occurs between the two levels whose spins are zero. But, E0 transition, namely the electric monopole transitions, becomes possible. Based on the E0 transition, we can further study the spectra and transitions of 0^+ excited states and the detailed properties of nuclear structure. With the accumulation of the experimental data of E0 transitions, a series of E0 transitions becomes possible. Studies have been done on ^{188}Os and ^{196}Pt[1]. The 0^+ states and E0 transitions in Zn, Ge, Se, Kr, Sr, Zr, Mo, Ru, Cd and Sn isotopes were studied theoretically and experimentally in Refs. [2—4]. The E0 transition in ^{64}Zn was calculated by IBM[5]; in Ref. [6] the electric monopole properties were studied systematically in the shell model, the geometric vibrational and rotational model, and algebraic model, pointing out that many of the large electric monopole strength ρ^2(E0) are associated with the shape mixing.

The Pd isotopes were still paid attention to in nuclear structure studies. Previous model calculations[7—14] demonstrated that they are $U(5)$ to $O(6)$ transitional nuclei for Pd, Xe and Ba isotopes. It was believed until recently that the Pd, Ba and Xe isotopes are typical examples of the $O(6)$-like nuclei[7,11,15—19]. But it has recently been shown[20—23] that one can describe the low-lying structure of the Pd, Xe and Ba isotopes by a transition from $U(5)$ to $SU(3)$. In this paper, we calculate the E0 transitions in the even-even $^{102-110}$Pd isotopes with both the $U(5)-SU(3)$ and the $U(5)-O(6)$ transition in the framework of the interacting boson model respectively, and compare our calculations with the experimental values.

The results show that the $U(5)-SU(3)$ transition description can better describe these isotopes than $U(5)-O(6)$.

2 The hamiltonian and E0 transition operator in IBM

More than twenty years ago, Arima and Iachello put

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forward the interacting boson model (IBM). In the IBM, the valence nucleon pairs are treated as bosons. It is a very effective phenomenological model for describing low-lying collective properties of nuclei across an entire major shell.

The general IBM Hamiltonian contains seven terms. In this paper, we take the following schematic Hamiltonian:

$$\hat{H} = \varepsilon_d \hat{n}_d + KQ \cdot Q + K_L L \cdot L, \quad (1)$$

where $$Q_\mu = (s^+ \tilde{d} + d^+ s)^2 + \chi (d^+ \tilde{d})^2_\mu, \quad (2)$$

and $$L_q = \sqrt{10}(d^+ \tilde{d})^{(1)}_q. \quad (3)$$

This Hamiltonian is able to give symmetries with the following parameter: $U(5): K = 0, \chi = 0$; $SU(3): \varepsilon_d = 0, \chi = -\sqrt{7}/2$; $O(6): \varepsilon_d = 0, \chi = 0$. $K_L L \cdot L$ term removes some of the degeneracy for different L values. If $\chi = -\sqrt{7}/2$, and K/ε_d lies in between 0 and ∞, the Hamiltonian, denoted by H^a, is in the transition between the $U(5)$ and the $SU(3)$. Similarly, if $\chi = 0$, the Hamiltonian, denoted by H^b, is in the transition between the $U(5)$ and the $O(6)$. The parameters in the Hamiltonian can be determined by fitting to the experimental spectra. In the framework of IBM, the E0 transition operator is[1]

$$\hat{T}(\mathrm{E0}) = \alpha (s^+ s)^0 + \beta (d^+ d)^0. \quad (4)$$

Since $\hat{N} = \hat{n}_s + \hat{n}_d$, $\hat{T}(\mathrm{E0})$ can also be written as

$$\hat{T}(\mathrm{E0}) = \alpha (\hat{N} - \sqrt{5}(d^+ d)^0) = \alpha \hat{N} + \beta' \hat{n}_d, \quad (5)$$

where $$\beta' = \beta/\sqrt{5} - \alpha. \quad (6)$$

Since the basis states are orthonormal and N is a constant for a given nucleus, the E0 matrix element becomes

$$\rho = \langle f | \hat{T}(\mathrm{E0}) | i \rangle = \beta \langle f | \hat{n}_d | i \rangle, \quad (7)$$

where i and f are the initial and final state corresponding to E0 transition. The reduced E0 transition strength is defined by

$$B(\mathrm{E0}) = e^2 R^4 \rho^2(\mathrm{E0}), \text{ with } R = 1.2A^{1/3}. \quad (8)$$

In the $U(5)$ limit, $\hat{N}$ and $\hat{n}_d$ are good quantum numbers[24], thus, $\hat{T}(\mathrm{E0})$ is diagonal and E0 transitions are forbidden. In the $SU(3)$ limit, $\hat{N}$ is a good quantum number, but $\hat{n}_d$ is not a good quantum number[25]. The $SU(3)$ limit allows the E0 transitions from β band $(2N-4,2)$ to g band $(2N,0)$[6]. In the $O(6)$ limit, N is a good quantum number, but $\hat{n}_d$ is not a good quantum number[26]. The E0 transition operator possesses the selection rules $\Delta\sigma = 0, \pm 2, \Delta\tau = 0$[6].

In the electric E2 transition, the E2 transition operator is

$$T(\mathrm{E2})^2_\mu = e_2 [(s^+ \tilde{d} + d^+ s)^2_\mu + \chi (d^+ \tilde{d})^2_\mu],$$

where e_2 is the effective charge.

3 Results and disscussion

The program PHINT[27] is used to calculate the spectra and E0 transitions. The parameters of the Hamiltonian and E0 transition are given in Table 1 (the Hamiltonian parameters are taken from paper[23]).

Table 1. Parameters of energy levels and E0 transitions for$^{102-110}$Pd.

	ε_d/MeV		K/MeV		K_L/MeV		e_2/MeV		β'	
Nucleus	H^a	H^b	H^a	H^b	H^a	H^b	H^a	H^d	H^a	H^b
^{102}Pd	0.6288	0.5650	-0.0084	-0.0079	0.0050	0.0093	0.1234	0.1284	0.3162	0.3162
^{104}Pd	0.6288	0.6150	-0.0054	-0.0079	0.0050	0.0093	0.1258	0.1258	0.3162	0.3162
^{106}Pd	0.5888	0.5880	-0.0074	-0.0079	0.0098	0.0740	0.1224	0.1262	0.3162	0.3162
^{108}Pd	0.4888	0.4950	-0.0074	-0.0089	0.0118	0.0093	0.1172	0.1208	0.3162	0.3162
^{110}Pd	0.4588	0.4450	-0.0074	-0.0079	0.0108	0.0093	0.1106	0.1189	0.3162	0.3162

Using the selected parameters, we calculated the values of the energy level, electric monopole strengths $\rho^2_{21}(\mathrm{E0})$, $\rho^2_{31}(\mathrm{E0})$, $\rho^2_{32}(\mathrm{E0})$ and the reduced transition rates $B(\mathrm{E0}; 0^+_2 \to 0^+_1)$ and $B(\mathrm{E2}; 0^+_2 \to 2^+_1)$, where $\rho^2_{ij}(\mathrm{E0}) = \rho^2(0^+_i \to 0^+_j)$; $\chi_{ijk}(\mathrm{E0/E2}) = B(\mathrm{E0}; 0^+_i \to 0^+_j)/B(\mathrm{E2}; 0^+_i \to 2^+_k)$[5]. The unit of $B(\mathrm{E0}; 0^+_2 \to 0^+_1)$ and $B(\mathrm{E2}; 0^+_2 \to 2^+_1)$ is $e^2 b^2$. The calculated and experimental values are shown in Table 2.

From Table 2, it is found that for the $^{102-110}$Pd isotopes the calculated values of $\rho^2_{21}(\mathrm{E0})$ and χ_{211} in the description of $U(5)$—$SU(3)$ are the same as in $U(5)$—$O(6)$ approximately. For the $^{102-106}$Pd isotopes, the calculated values of $\rho^2_{21}(\mathrm{E0})$ are in good agreement with experimental values. But, in $U(5)$—$O(6)$, the calculated values of $\rho^2_{31}(\mathrm{E0})$ and $\rho^2_{32}(\mathrm{E0})$ are zero respectively, which are not in agreement with experimental values. For

the $U(5)-SU(3)$ transition, the calculated values of $\rho^2_{31}(E0)$ and $\rho^2_{32}(E0)$ are not zero, especially for ^{102}Pd and ^{110}Pd, the calculated values of $\rho^2_{31}(E0)$ are in good agreement with experimental values. The value of $\rho^2_{32}(E0)$ are generally larger than $\rho^2_{31}(E0)$[4]. This is caused by the fact that both of the 2 d-boson components and the pairing-vibrational components have equally large contributions to $|\rho(0_3^+\rightarrow 0_2^+)|$, while there is no contribution from the 2 d-boson components to $|\rho(0_3^+\rightarrow 0_1^+)|$. In the $U(5)-SU(3)$ transition, the value of $\rho^2_{32}(E0)$ is larger than $\rho^2_{31}(E0)$ for each $^{102-110}$Pd isotopes. As a consequence, it was found from this work that the even-even $^{102-110}$Pd could be well described by the $U(5)-SU(3)$ transitional dynamics.

Table 2. Comparison of the experimental values[6] for $^{102-110}$Pd with the calculation.

Nucleus		$B(E2)$	$\rho^2_{21}(E0)\times 10^3$	$B(E0)\times 10^4$	$\chi_{211}\times 10^3$	$\rho^2_{31}(E0)\times 10^3$	$\rho^2_{32}(E0)\times 10^3$
^{102}Pd	Exp		4.0(15)	3.95		<0.3	
	Cal[a]	0.040	4.15	4.10	10.3	0.03	4.53
	Cal[b]	0.121	4.04	3.99	3.29	0	0
^{104}Pd	Exp	0.038(37)	4.7(20)	4.77	12.6		
	Cal[a]	0.058	2.53	2.56	4.41	0.01	2.86
	Cal[b]	0.149	5.36	5.44	3.65	0	0
^{106}Pd	Exp	0.089(21)	14(3)	14.7	16.5		
	Cal[a]	0.155	8.63	8.98	5.97	0.10	9.50
	Cal[b]	0.183	8.67	9.02	4.93	0	0
^{108}Pd	Exp	0.134(31)	<3	<3.19	<2.38		
	Cal[a]	0.182	19.5	20.8	11.4	0.34	21.9
	Cal[b]	0.190	22.8	24.3	12.8	0	0
^{110}Pd	Exp	0.116(22)	3.4(6)	3.72	3.21	0.48(15)	
	Cal[a]	0.249	32.9	35.9	14.4	0.63	39.8
	Cal[b]	0.214	30.7	33.5	15.7	0	0

The 0^+ states spectra of the $^{102-110}$Pd isotopes are given in Figs. 1 to 5, in which, the electric monopole strength is multiplied by a factor of 10^3. Agreement between theory and the experiment is obtained.

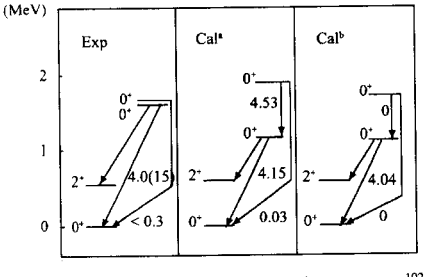

Fig.1. Electromagnetic decays of 0^+ states in ^{102}Pd.

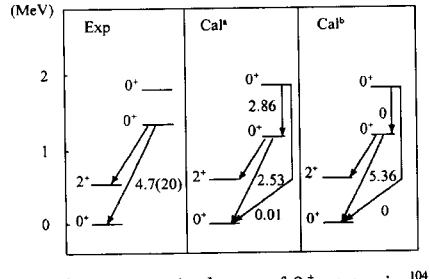

Fig.2. Electromagnetic decays of 0^+ states in ^{104}Pd.

Moreover, χ_{211} is an important value in nuclear structure characterizations. χ_{211} is equal to $4\beta^2$, where β denotes the equilibrium deformation[4]. From Table 2, it

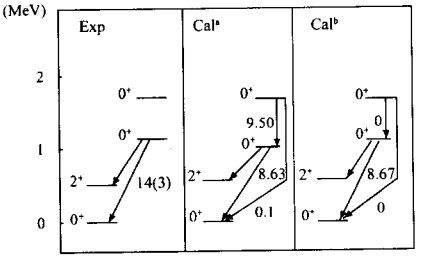

Fig.3. Electromagnetic decays of 0^+ states in ^{106}Pd.

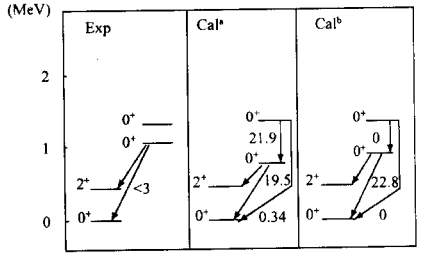

Fig.4. Electromagnetic decays of 0^+ states in ^{108}Pd.

was found that the experimental value of χ_{211} for ^{106}Pd is the largest, which means the deformation is the largest. On the contrary, the experimental values of χ_{211} for ^{108}Pd is the smallest, so the deformation is smaller. There are some discrepancies between calculated and experimental values for each nucleus.

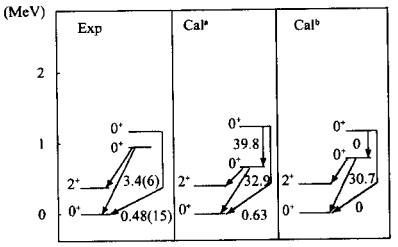

Fig.5. Electromagnetic decays of 0^+ states in ^{110}Pd.

4 Conclusion

We have given a detailed study of the E0 transition in even-even $^{102-110}$Pd isotopes with the descriptions of the $U(5)-SU(3)$ and the $U(5)-O(6)$ transition in the framework of the interacting boson model respectively. The results indicate that even-even $^{102-110}$Pd isotopes are better described by the $U(5)-SU(3)$ transition rather than the $U(5)-O(6)$ transition.

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原子核形状演变的又一个特征指标 E0 跃迁及对 $^{102-110}$Pd 偶偶核的应用*

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摘要　利用相互作用玻色子模型分别在 $U(5)-SU(3)$和 $U(5)-O(6)$描述下研究了$^{102-110}$Pd 偶偶核的电单极跃迁. 研究表明,这些偶偶 Pd 核能够用 $U(5)-SU(3)$更好地描述.

关键词　E0 跃迁　低能正宇称集体态　核形变

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