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Nuclear Structure of Ce Isotopes Using IBM Results

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Abstract:

The Ce isotopes of even mass number (A=130 to A=136) were studied by using the Interacting Boson Model (IBM) results. The electric quadruple transitions and energy levels of these isotopes were investigated for there are experimental evidences that these nuclei have a gamma soft traixialrotor O(6) like. The calculated results were compared with the available experimental data, the results were in general good agreement.

Introduction:

The even mass Ce isotopes are a part of interacting region, so they are a matter of many experimental and theoretical investigation. The interest in the region has been initiated by the IBM-2 nuclear models of Arima and Iachello (1978) which predict a new nuclear symmetry (limits) that vary from SU(3) for well deformed nuclei to SU(5) for spherical like and O(6) for transitional region.

The aim of this work is to study level structure, excitation energy, gamma ray transition probability and compare the theoretical results to the experimental data.

Theory:

The interacting boson approximation (IBA) Model of Arima and Iachello [1] [provides a unified description of collective nuclear states n terms of a system of interacting bosons. The bosons may have angular momentum L=0 (S-boson) and L=2 (d-boson). In the simplest version with no distinction between proton and neutron (IBA-1)[2], the calculation of level energies of positive party is based on a computer code PHINT which diagonalise the Hamiltonian of the form:[3]

$$H = \epsilon_d\, n_d + a_0 P.P + a_1 L.L + a_2 Q.Q + a_3 T_3.T_3 + a_4 T_4.T_4 \dots\dots\dots\dots (1)$$

Where ϵ_d represent the d-boson energy, n_d is the number of d- boson, P,L,Q are the pairing, angular momentum and quadruple operators respectively and the last terms are octupole and hexadecapole interaction terms.

The quadruple electric transition probability from initial state to final state is given by the expression [4]:

$$B(E2; I_i \rightarrow I_f) = 1/(2I_i + 1)|< B(E2; I_i \rightarrow I_f) >|^{2} \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where the E2 transition operator in the IBA-1 is

$$T^{E2} = \alpha[d^{+} \times s + s^{+}d]^{(2)} + \beta[d^{+} \times d]^{(2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

And extend model that account for the independent degrees of freedom of the proton and neutron boson is the IBM-2 model. The standard Hamiltonian of this model is:

$$H = \epsilon_{\pi}\, n_{d\pi} + \epsilon_{\vartheta}\, n_{d\vartheta} + KQ_{\pi}.Q_{\vartheta} + V_{\pi\pi} + V_{\vartheta\vartheta} + H_m \ldots\ldots\ldots\ldots(4)$$

Where ϵ_{π} *and* ϵ_{ϑ} refer to the single d-boson energies, K is the strength of quadruple - quadruple interaction between proton and neutron boson. The H_m term is known as the majorna term which is responsible for the effect of shifting mixed symmetry state. The energy level are obtained by diagonalizing this Hamiltonian by NPBOS code [5]. The best fit to the experimental spectrum is obtained by using the values of the parameters in the Hamiltonian of the two models. Table (1) shows the two models parameters used in this study.

Result and Discussion:

1. Excited Energy state

The even parity states of four Ce isotopes were studied. The study includes the ground band ($0_1^+, 2_1^+, 4_1^+, 6_1^+, 8_1^+$), and quasi beta band ($0_2^+, 2_2^+, 4_2^+$) and the quasi gamma band ($2_3^+, 3_1^+$) [6]. The results are compared with the experimental values[7]. There is a reasonable agreement between the experimental and the model results.

Fig. (1) shows the excited energy state of Ce-130. It demonstrates the agreement between the experimental values and the results of IBM-1 and IBM-2, the values of the ratio $E4_1^+/E2_1^+$ is: 2.673 (IBM-1), 2.602 (IBM-2), 2.797 (exp.), these values enables us to locate this nucleus within O(6) limit.

The excited energy states of Ce-132 are shown in fig. (2), from which w can see that the state 0_2^+ has the following energies: 1.307 MeV (IBM-1) and 1.2635 MeV (IBM-2) and it is far a way from the 4_1^+ state whose energy is: 0.818 MeV (IBM-1) and 0.861 MeV (IBM-2). The ratio $E4_1^+/E2_1^+$ is : 2.697 (IBM-1) and 2.609 (IBM-2) and 2.637 (exp.). This figure also shows that 8_1^+ state has the highest experimental energy (2.324 MeV) and 2.371 MeV, 2.494 MeV in IBM-1 and IBM-2 respectively. These results assures the correctness of the way we use in choosing the Hamiltonian parameter. They also show that Ce-132 is in O(6) limit.

As we have seen the above two isotopes belong to O(6) limit of IBM-2 , this enables us to use the same method of choosing the Hamiltonian parameters to Ce-134 isotopes. The $E4_1^+/E2_1^+$ ratio result is: 2.07 (IBM-1), 2.507 (IBM-2) and 2.234 (exp.). All results of this isotopes are shown in figure (3). The disagreement between IBM-1 results and the experimental results for the states ($2_2^+, 4_2^+, 6_1^+$) is due to failure in choosing the correct IBM-1 parameters for these states. In opposite to this, we see a good agreement between IBM-2 results and the experimental results due to the flexibility that this model affords in choosing the parameters.

Taking into account the results of Ce-134, we can now correctly chose the parameters of IBM-1 Hamiltonian for the isotope Ce-136. In particular we account for the EPS parameter in computing the states of Ce-136 isotope since this parameter is important in U(5) limit computing [8]. The ratio of $E4_1^+/E2_1^+$ is: 2.001 (IBM-1), 2.357 (IBM-2) and 2.37 (exp.). These results are in the range of U(5) limit which indicates that Ce isotopes are transformable from O(6) to U(5) limit. Figure (4) confirms these results.

2. Quadrupole electric transition probability:

We have calculate the quadruple transition probability B(E2) using the parameters shown in equation (3). The parameters $\alpha_2 and\ \beta_2$ in this equation vary smoothly from O(6) limit for the first three Ce- isotopes to U(5) limit for the other isotopes. This is in good agreement with Wanners study [9]. Table (2) shows a comparison

3. The branching ratio:

To support our conclusion that the Ce-isotopes belong to the O(6) limit, we study the branching ratios for these isotopes. The results are summarized in table (3), were a comparison with the corresponding experimental results is also presents. This table shows the good agreement between the calculated results and O(6) one.

4. Conclusion:

The study of Ce-isotopes performed here shows that this series of nuclei are an example of the O(6) limit that transform for high isotopes to U(5) limit. We have also presented a complete set of structure calculations that are in good agreement with the experimental results. This agreement has been obtained as a computing models.

Table(1): The IBM-1 and IBM-2 Hamiltonian's parameters

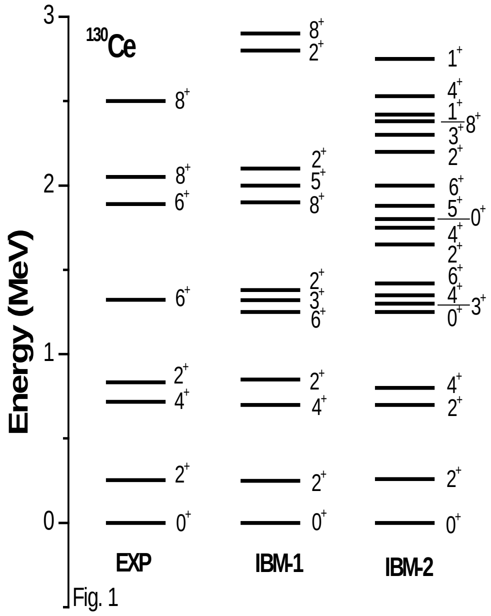
A	N	EPS	A0	A1	A2	A3	A4	CHI
130	9	0.00	0.254	0.0130	-0.0076	0.127	-0.006	-1.0170
132	8	0.00	0.270	0.0187	-0.0025	0.140	-0.009	-1.1265
134	7	0.00	0.450	0.0210	-0.0003	0.180	-0.160	-1.0173
136	6	0.41	0.002	0.0091	-0.0210	0.006	-0.001	-1.3230
A	**ED**	**RKAP**	**CHN**	**CON**	**C2N**	**C4N**	**RKMJ1=RKM3**	**RKMJ2**
130	0.580	-0.182	-0.82	0.140	0.120	0.110	-0.06	0.146
132	0.623	-0.186	-0.78	0.132	0.100	0.110	-0.06	0.151
134	0.745	-0.190	-0.81	o.112	0.090	0.100	-0.06	0.132
136	0.680	-0.195	-0.84	0.108	0.088	0.094	-0.06	0.122

Table (2): A comparison between IBM-1 and experimental results for B(E2) values

		A=130		A=132		A=134		A=136	
I_i	I_f	Exp.	IBM-1	Exp.	IBM-1	Exp.	IBM-1	Exp.	IBM-1
2_1	0_1	0.3401	0.3453	0.3760	0.3641	0.2130	0.2042		0.1200
2_2	2_1		0.3240		0.4669		0.2722		0.1645
2_2	0_1		0.0275		0.0052		0.0003		0.0136
4_1	2_1	0.5590	0.4831	0.3500	0.4951	0.1680	0.2719		0.2131
3_1	2_2		0.3762		0.3799		0.2021		0.0205
4_2	2_2		0.3087		0.2859		0.1484		0.1434
5_1	3_1		0.2937		0.2757		0.1374		0.1239
5_1	4_1		0.1247		0.1236		0.0626		0.0628
6_1	4_1	0.3920	0.5320	0.5500	0.5342	0.075	0.2829		0.2769
6_2	6_1		0.1504		0.1633		0.0836		0.0627
6_2	4_2		0.4024		0.3614		0.1792		0.1843

Table (3) : Branching ratio of Ce isotopes using IBM-1

I_i	I_f / I'_f	A=130	A=132	A=134	A=136
2_1	$0_1/2_1$	0.0846	0.0110	0.0010	0.0824
4_2	$4_1/2_2$	0.5391	0.8603	0.8950	0.6521
3_1	$2_1/2_2$	0.1010	0.0173	0.0015	0.1429
3_1	$4_1/2_2$	0.3617	0.3967	0.4008	0.2005



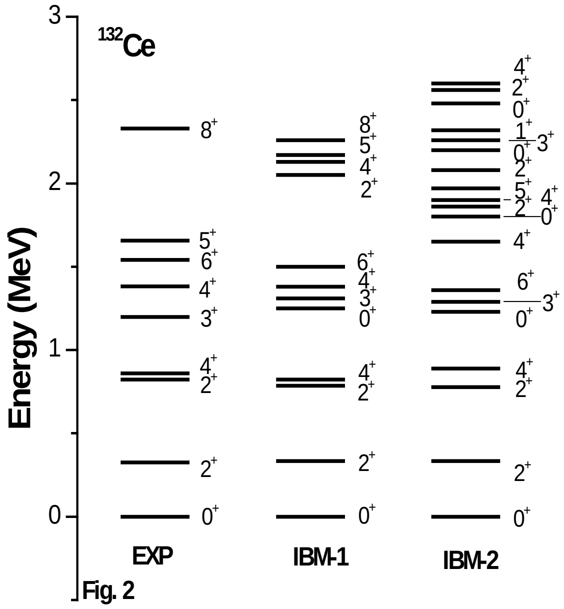
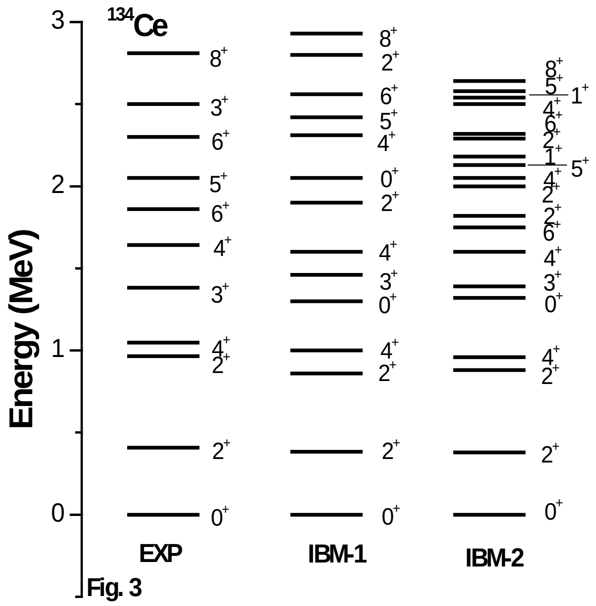


Figure: (1and2) The energy levels of Ce -130 and Ce -132.



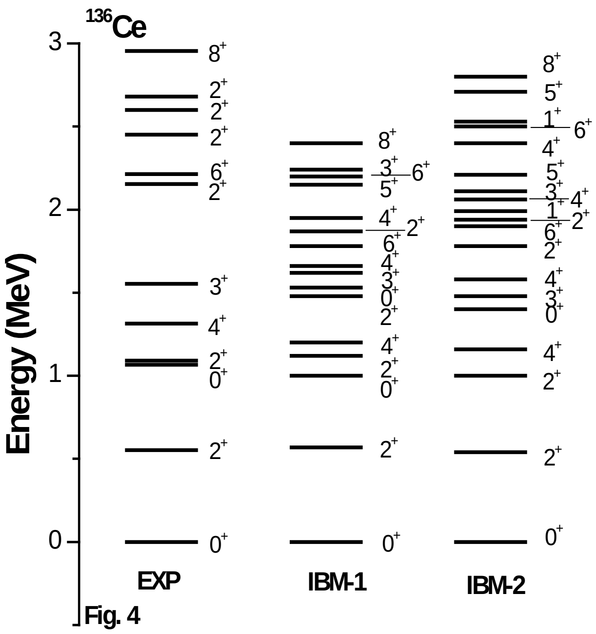


Figure: (3and4) The energy levels of Ce -134 and Ce -136.

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