Letter to the Editor

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Low lying energy levels of odd mass Ir isotopes

C. R. Chandran, M. L. Narasimha Raju, G. Satyanarayana and K. Parthasaradhi

Laboratories for Nuclear Research, Andhra University, Waltair-4.

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Eversince de Shalit (1961) proposed the core-excitation model for non-deformed odd A nuclei, it attracted the attention of many investigators in view of its simplicity. The experimental data on the E_2 and M_1 transition probabilities and nuclear moments of several nuclei in the spherical region were satisfactorily explained (Braunstein & de Shalit 1962, Seetharamanath *et al* 1971a, 1971b) within the frame-work of core excitation model. In particular the transition probabilities of various transitions de-exciting from the low-lying levels and the nuclear moments of the ground and excited states in ^{197}Au were explained (Braunstein & de-Shalit, 1962) with large degree of success on the basis of the core-excitation model. Recently Seetharamath *et al* (1971b) studied the level structure of ^{193,195,197,199}Au within the frame-work of this model and the levels were well reproduced.

In view of many striking similarities between Au and Ir nuclei it is interesting to study the applicability of the core-excitation model to Ir nuclei. Such a study for Ir nuclei is particularly interesting since Ir nuclei lie just at the border of deformed region. Recently Avida *et al* (1968) and Berant *et al* (1972) satisfactorily explained the experimental data on transition probabilities and nuclear moments only, in ^{191}Ir and ^{193}Ir within the frame-work of the core-excitation model. The values of the electromagnetic properties are given in table 1. Sufficient data on ^{189}Ir are not available to test the applicability of the core-excitation model. Hence, in the present paper an attempt is made to predict the energy levels in all the odd mass Ir isotopes on the basis of the core-excitation model, about which so far no attempt has been made. Such an attempt also throws some light on the nature of the core-particle interaction. However, for comparison the levels are also predicted using intermediate coupling model. The level diagram of the Ir isotopes is shown in figure 1.

With the core-excitation model, the four excited levels in ^{189,191,193}Ir with spins 1/2, 5/2, 3/2 and 7/2 can be described as members of the multiplet which

Table 1. Electromagnetic properties of odd mass Ir nuclei

Nuclei	Transition		$B(M_1)$	$B(E_2)$
^{191}Ir	$\|1/2\rangle \rightarrow \|3/2\rangle_1$	Theo:	0.0071 ±0.	0.173
		Expt:	0.0037 ±0.001	0.14 ±0.03
	$\|3/2\rangle_2 \rightarrow \|1/2\rangle$	Theo:	0.344	0.03
		Expt:	0.52 ±0.2	0.2 $^{+0.4}_{-0.2}$
	$\|3/2\rangle_2 \rightarrow \|3/2\rangle_1$	Theo:	0.0107	0.185
		Expt:	0.174 ±0.007	0.104 ±0.05
	$\|5/2\rangle \rightarrow \|3/2\rangle_1$	Theo:	0.136	0.204
		Expt.	0.134 ±0.015	0.38 ±0.1
	$7/2 \rightarrow 5/2$	Theo:	0.184	0.241
		Expt:	0.23 ±0.06	0.23 ±0.12
	$\|7/2\rangle \rightarrow 3/2\rangle_1$	Theo:		0.188
		Expt:		0.265 ±0.06
	$\mu_{(3/2)1}$	Theo:	0.14591	Theo: 0.644
		Expt:	0.14589±0.00003	Expt: 1.0 ±0.5
	$\mu_{1/2}$	Theo:	0.5414	
		Expt:	0.5415 ±0.005	
^{193}Ir	$\|1/2\rangle \rightarrow 3/2\rangle_1$	Theo:	0.0074	0.196
		Expt:	0.0065 ±0.001	0.153 ±0.02
	$3/2 \rightarrow 1/2$	Theo:	0.367	0.00016
		Expt:	0.5	0.00015
	$\|5/2\rangle \rightarrow 3/2\rangle_1$	Theo:	0.172	0.196
		Expt:	0.19 ±0.03	0.34 ±0.15
	$\|3/2\rangle_2 \rightarrow 3/2\rangle_1$	Theo:	0.0058	0.134
		Expt:	0.016	0.047
	$7/2 \rightarrow 5/2$	Theo:	0.191	0.145
		Expt:	0.27 ±0.06	0.095 ±0.05
	$7/2 \rightarrow 3/2$	Theo:		0.21
		Expt:		0.30 ±0.06
	$\mu_{(3/2)1}$	Theo:	0.1559	Theo: 0.75
		Expt:	0.1589 ±0.0009	Expt: 1.0 ±0.5
	$\mu_{1/2}$	Theo:	0.5470	
		Expt:	0.477 ±0.02	
	$\mu_{5/2}$	Theo:	1.405	
		Expt:	0.68 ±0.11	

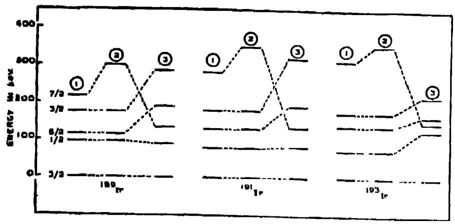

Figure 1 Low lying energy levels in odd mass iridium nuclei.
1. Levels as predicted by the core excitation model.
2. Experimental levels.
3. Levels as predicted by the intermediate coupling model.

results from the coupling of the $d_{3/2}$ orbit of the 77th proton or the 79th proton hole, to the 2_+ state of the core. The core-particle interaction can in general be represented by the sum of scalar products of irreducible tensors :

$$H_{\text{int}} = \sum f_K(T_c{}^K . T_K{}^K) \tag{1}$$

where $T_c{}^K$ operates on the degrees of freedom of the core only and $T_P{}^K$ operates on the degrees of freedom of the particle only and f_k is the strength of the interaction Then the energy levels are given by

$$E_3 = E_0 + (-1)^{\frac{1}{2}+J} \sum_K C_K \begin{Bmatrix} 2 & 3/2 & J \\ 3/2 & 2 & K \end{Bmatrix} \quad \ldots \quad (2)$$

$$C_K = f_K < J_C \| T_C{}^K \| J_C > < J_P \| T_P{}^K \| J_P >$$

where E_0 is the centre of mass parameter. The allowed values of K are 0, 1, 2 and 3 for Ir nuclei. Leaving alone $K = 0$ term which causes only shift of the centre of gravity the terms which split the multiplet are the terms with $K = 1$, $K = 2$ and $K = 3$. However, the $K = 2$ term is found to be small and neglected in the case of Au nuclei.

As in the case of Au nuclei we have neglected $K = 2$ term and attempted to predict the energy levels following the procedure outlined (Seetharamanath *et al* 1971a, b, Narasimharaju *et al,* 1971). The value of E_0 is varied from the energy of the 2_+ state in the neighbouring ^{188}, ^{190}, ^{192}Os nuclei to the energy of 2_+ state in the neighbouring ^{190}, ^{192}, ^{194}Pt nuclei respectively. However, the energy levels were not reproduced. In fact the predicted spin sequence is 1/2, 3/2, 5/2 and 7/2, whereas, the observed sequence is 1/2, 5/2, 3/2 and 7/2 as can be seen from figure 1. So we have included $K = 2$ term in expression (2). Varying E_0 between the limits specified above, we have attempted to predict the four energy levels.

The energy levels are also predicted using the intermediate coupling model (Chowdry *et al*, 1963). In these calculations the last odd proton available to the $3S_{1/2}$ and $d_{3/2}$ states is coupled to the even-even core of the corresponding neighbouring Pt nuclei and the resulting Hamiltonian is diagonalized upto the first two phonon states to get the energy eigen values. Since Ir isotopes fall in the 2_+ state of the corresponding even-even Pt core the parameters are varied to get the best fit. The best fit is obtained at a lower energy value of E_0, the energy of the first excited 2_+ state of Pt isotopes, indicating the deformation. The calculations are performed on IBM 1130 computer of the Andhra University. The set of parameters used are given in table 2.

Table 2. Values of the parameters used in the intermediate coupling model

Isotope	E_0(MeV)	Coupling strength	Energy spacing $E_{1/2}-E_{3/2}$ (MeV)
^{189}Ir	0.186	1.1	0.27
^{191}Ir	0.186	1.4	0.31
^{193}Ir	0.186	0.6	0.29

The energy levels predicted on the basis of core-excitation and intermediate coupling models are given in table 3. From table 3, it can be seen that the agreement between the predicted and the observed energy levels is in general satisfactory with the core-excitation model calculations. The value of the parameter

Table 3. Low-lying energy levels in odd mass Ir nuclei

Isotope		E_0(MeV)	C_1	C_2	C_3	$E_{1/2}$	$E_{5/2}$	$E_{3/2}$	$E_{7/2}$
^{189}Ir	Theo 1 :	0.296	+0.624	−0.667	−3.244	0.094	0.114	0.176	0.242
	Theo 2 :					0.092	0.189	0.284	0.136
	Expt :					0.094	0.114	0.176	0.300
^{191}Ir	Theo 1 :	0.317	+0.494	−0.675	−3.294	0.082	0.129	0.179	0.282
	Theo 2 :					0.084	0.190	0.320	0.190
	Expt :					0.082	0.129	0.169	0.349
^{193}Ir	Theo 1 :	0.328	+0.281	−0.561	−2.638	0.073	0.139	0.180	0.317
	Theo 2 :					0.130	0.170	0.210	0.150
	Expt :					0.073	0.139	0.180	0.357

Theo 1 : Core-excitation model
Theo 2 : Intermediate Coupling model
Expt : Experimental value

E_0 in core-excitation model calculations indicates that the four low-lying levels in odd mass Ir nuclei can be described as resulting from a coupling of the $d_{3/2}$ orbit of the 78th proton hole to the 2_+ state of the core. The present results do not favour the odd proton being coupled to the 2_+ state of the core. For values of E_0 close to the energy of the 2_+ state in Os even-even nuclei, the energy of the 7/2 state is too low for comparison. This conclusion is also supported by the calculations of Avida *et al* (1968) for ^{193}Ir. The reduced matrix elements $< 0||T_C{}^2||2 >_{\rm Avida}(=1)$ and $< 0||T_C{}^2||\ 2 >_{\rm Berant}\ (=1)$ are in good agreement with $< 0||T_C{}^2||\ 2 >_{^{192}\rm Pt}\ (= 1.17)$ and disagrees with $< 0||T_C{}^2||\ 2 >_{^{192}\rm Os}\ (= 2.63)$.

Finally it is interesting to compare the applicability of the core excitation model to Au and Ir nuclei. In the case of Au nuclei, a simple dipole-octupole interaction between the core and the particle could explain the level structure, whereas in the case of Ir nuclei the quadrupole interaction also plays an important role. The relative strengths of the dipole, quadrupole and octopole interactions can be determined only if the values of the reduced 'matrix elements' $< J_C||T_C{}^K||J_C >$ and $< J_P||T_P{}^K||J_P >$ for $K = 1, 2, 3$ are known. The presence of the quadrupole effect in Ir nuclei is not entirely unexpected since they lie in the intermediate region between the deformed and spherical nuclei.

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