ISOMERISM IN ODD AND ODD-ODD NUCLEI WITH MASS NUMBER 185 ≤ A ≤ 191

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1. INTRODUCTION

During last years, substantial progress was accomplished in the elaboration of the theoretical methods which can be applied to the description of the transitional even nuclei[1-3]. The situation is much less satisfactory when odd-A nuclei are concerned, where the experimental data must be still compared with models which were constructed for strongly deformed or spherical nuclei. Although the imperfection of this kind of comparison for transitional nuclei is well known[3], it is certainly interesting to see how far the "extreme" models can be extrapolated.

The first important step in the study of odd-A nuclei is the location of the single-particle levels. These yield information on the average field of the nucleus. Experimentally, when radioactivity studies are concerned, one of the most unambiguous methods of locating some single-particle levels is the study of isomerism and the determination of log ft values.

In this paper we present some results concerning the study of isomeric states in a number of odd-A and doubly odd nuclei in the Pt region. In some cases these results are correlated with decay scheme investigations. Due to the experimental method used, only isomers with half-lives longer

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than a few seconds or in the nanosecond to microsecond range could be detected. The assignment of the Nilsson model characteristics is attempted for some of the observed excited states in the nuclei investigated.

2. ISOMERS WITH HALF-LIFE LONGER THAN ≈ 10 sec

The on-line and off-line measurements for this range of half-lives were done using multispectrum analysis on gamma or conversion electron spectra [further experimental details have been published elsewhere[4]]. In some cases a chemical separation of the mass separated samples was performed. A summary of these data is presented in Table 1, which also includes data noted elsewhere[5-7]. Some comments and examples are discussed below.

2.1 Isomerism in odd-A nuclei

Heavier isotopes of mercury (A ≥ 193) possess isomeric states which are currently assigned to the close-lying $i_{13/2}$ and $p_{1/2}$ or $p_{3/2}$ spherical model orbits[8-10]. For lighter isotopes of mercury the many different orbitals deduced from Nilsson diagram suggest the existence of isomerism (cf. Fig. 3), assuming the existence of deformation.

In ^{185}Hg, three different half-lives seem to be present. The A=185 chain, however, possess a rather strong α branching[4] and at present we cannot completely exclude that some of the half-lives attributed to the 185 chain belong to the 181 one. It is interesting to note that isomerism is also expected to exist in ^{189}Hg and ^{191}Hg. Our data and those of Ref. 11 indicate that a high spin, probably $11/2^-$ state in ^{189}Au and ^{191}Au, is strongly fed from the corresponding decay of the Hg parent. Therefore, the spin of the 8.7 ± 0.2 min ^{189}Hg and 50 min ^{191}Hg must be high. We have found the existence of a 7.7 ± 0.2 min isomer of presumably low spin in ^{189}Hg, by observation of the decay of the individual gamma lines. A similar search in ^{191}Hg was unsuccessful possibly due to a similarity in half-life to that of the high-spin state.

The isomerism in odd-A gold isotopes may probably be attributed to the close lying $11/2^-$ and $3/2^+$ states, which can be identified with $h_{11/2}$ and $d_{3/2}$ shell-model states or $11/2^-$ (505) and $3/2^+$ (402) Nilsson states. In this work we have investigated in more detail the decay of the 4.55 min

Table 1

Isomers with $T_{1/2} \gtrsim 10$ sec

Nuclide	Half-life	Main transitions observed (keV)	Spin	α-decay data[a)]	Comments
^{189}Hg	7.7 ± 0.2 min	201,229,238,248,279			
	8.7 ± 0.2 min	204,388,399,434,500 and others			
^{187}Hg	2.4 ± 0.2 min	103,220,233,271		2.2 ± 0.3 min	b
	1.6 ± 0.3 min	112,335			
^{185}Hg	50 ± 2 sec	189,222,258		48.0 ± 1.5 sec	c
	26 ± 3 sec	211,292		17 ± 5 sec	
	155 ± 20 sec	243,331			d
^{189m}Au	4.55 ± 0.10 min	166,322	$11/2^-$		e
^{187}Au	6.4 ± 1.3 min	181			d
	8.5 ± 0.7 min	185,190,251			
^{186m}Au	2 min	191	(1,2)		f
^{185}Au	4.2 ± 0.3 min	311			
	6.8 ± 0.5 min	145			
^{185}Pt	33 ± 5 min	120,135,197 and others			
	70 ± 10 min	153 and others			
^{186m}Ir	1.7 h	137,297,986 and others	(2-)		f

a) P.G. Hansen, H.L. Nielsen, K. Wilsky, M. Alpsten, M. Finger, A. Lindahl, R.A. Nauman and O.B. Nielsen, Nuclear Phys. 148, 249 (1970).

b) Relative position of isomers not known.

c) Assigned as ground state in P.G. Hansen, H.L. Nielsen, K. Wilsky, M. Alspten, M. Finger A. Lindahl, R.A. Nauman and O.B. Nielsen, Nuclear Phys. 148, 249 (1970).

d) Existence of isomerism is tentative at present.

e) Previous investigations of this isomer are given in: A. Fourrier, J. Jastrzebski, P. Paris and J. Treherne, C.R. Acad. Sci. Paris 263, 1182 (1966); C. Heiser, K.F. Alexander, F.F. Brinckmann, N. Nenov, W. Neubert and H. Rotter, Nuclear Phys. A96, 327 (1967).

f) Ground state has higher spin and longer half-life.

isomeric state in ^{189}Au. The results of this investigation are summarized in the next section, which deals with a nanosecond isomer discovered in the decay of ^{189m}Au.

2.2 Isomerism in odd-odd nuclei

From our data[4] and from data given in the literature[12-14], it is known that the radioactive decay of odd-odd nuclei in this region very often populate high-spin (up to 6^+) states in even-even nuclei. It is the case, for example, in the decay of ^{184}Au, ^{186}Au, ^{184}Ir, and ^{186}Ir, and they must therefore have rather high spins. In our investigation these odd-odd nuclei are obtained from the decay of even parents, and therefore a "spin-gap" exists between the 0^+ state of mother even-nuclei and presumably the ground state of odd-odd nuclei. This "spin-gap" may favour the existence of isomerism. We have found the isomerism in the case of ^{186}Au and confirmed[12] it in the case of ^{186}Ir. The search for isomerism in ^{184}Au and ^{184}Ir was unsuccessful. Our studies and those of Zaitseva et al.[15] indicate the configurations for the ground and excited states of ^{186}Ir, as shown in Fig. 1.

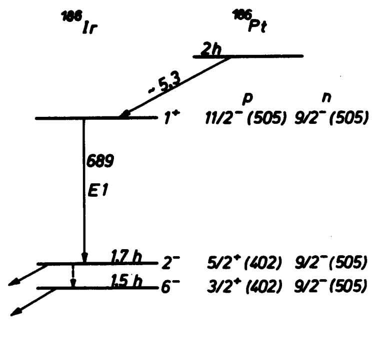

Fig. 1

3. ISOMERS IN THE NANOSECOND RANGE

At present, only off-line measurements have been performed within this part of our program. Standard nanosecond timing methods were used. A summary of the data obtained is presented in Table 2 which also includes data reported elsewhere[16,17]. Some examples are discussed below.

Table 2

Nanosecond isomers

Nuclide	Metastable state half-life (nsec)	Main transitions observed from the decay of metastable states (keV)	Comment
$^{185m_1}Os$	3000 ± 400	97	a
$^{185m_2}Os$	780 ± 50	157 (M1)	
$^{185m_1}Ir$	2.1 ± 0.2	235 ± 5	
$^{185m_2}Ir$	19 ± 3	655 ± 5	b
$^{187m_1}Ir$	11.5 ± 0.3	106 (E2)	
$^{187m_2}Ir$	155 ± 15	247 (M1)	
^{189m}Ir	11.5 ± 0.3	94 (E2+M1)	c
^{191m}Ir	4.17 ± 0.10	82 (E2+M1)	d
^{189m}Pt	464 ± 25	166 (E2)	

a) The existence of this isomer is tentative.

b) The metastable state can belong to the ^{185}Pt or A = 181 chain.

c) A previous measurement of this half-life was reported in: J. Jastrzebski, H. Abou-Leila and N.N. Perrin, Nuclear Phys. 70, 392 (1965).

d) A previous measurement of this half-life was reported in: A.W. Sunyar, Phys. Rev. 98, 653 (1955).

3.1 Decay of ^{189}Au and isomerism in ^{189}Pt

Detailed nuclear spectroscopy of ^{189}Hg and ^{189}Au was performed within our program and also elsewhere[6,7,11,18-20]. The gamma-ray spectrum of the 28 min ^{189}Au ($3/2^+$) is rather complicated, but only two transitions are assigned to the decay of the 4.55 min ^{189m}Au ($11/2^-$), i.e. 166 keV and 322 keV. By performing X_K-gamma coincidence we discovered that the 166 keV transition in ^{189}Pt is delayed ($T_{1/2}$ = 464 nsec). Investigation of the decay of the delayed coincidences has shown that the isomeric state in ^{189}Pt is populated only from the decay of the 4.55 min ^{189m}Au although the 166 keV transition is observed from the decay of both gold isomers. Therefore we postulate that some low-energy, still undiscovered, transition is responsible for the isomerism in ^{189}Pt. Another result from the delayed coincidence measurements was that the isomer in ^{189}Pt is fed not only by EC + β^+ decay, but also by the 322 keV transition. The simplified decay scheme is presented in Fig. 2. In this figure we indicate that the 166 keV transition goes to the ground state, but with currently available data it can also go to a 6.3 keV or 45.7 keV state as postulated in Refs. 11 and 18. Assuming a total decay energy of 2.9 ± 0.5 MeV [21], the log ft values for the isomeric state and the level depopulated by the 322 keV transition are 4.7 ± 0.3 and 5.4 ± 0.3, respectively. This indicates an allowed unhindered (au) transition in both cases.

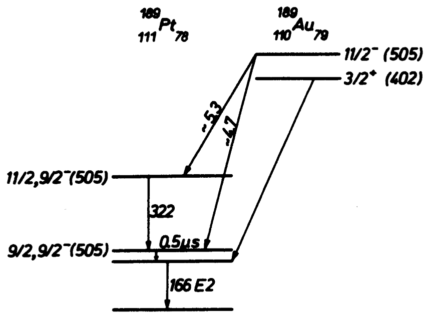

Fig. 2

The explanation of these low log ft values comes quite naturally if one accepts that ^{189}Pt is deformed and that the isomeric state has 9/2$^-$ (505) character, and a rotational level built on it has an energy 322 keV higher. In this case the β transition proceeds between the 11/2$^-$ (505) state in ^{189}Au and members of the 9/2$^-$ (505) quasi-band. The inertial parameter of this band would be $\hbar^2/2y$ = 29.2 keV, as compared to the values 44.4 keV and 49.3 keV, respectively, in ^{188}Pt and ^{190}Pt for the quasi-ground band. This reflects the well-known fact that an odd-A nucleus has a higher moment of inertia than the neighbouring even nuclei. The ratio of the experimental ft values to this band is 5 ± 2 and that calculated from the square of the Clebsch-Gordan coefficients is 5.4.

The predicted Nilsson states[22] for ε = 0.15 are shown in Fig. 3. A compression factor of 2, recommended by Reich and Bunker[23] for the rare earth nuclei, was used in the preparation of this figure. In the ground state the 111 neutron is placed in the 1/2 (510) orbit for this deformation. The single-particle levels of ^{185}W [24,25] ^{187}Os [12], and

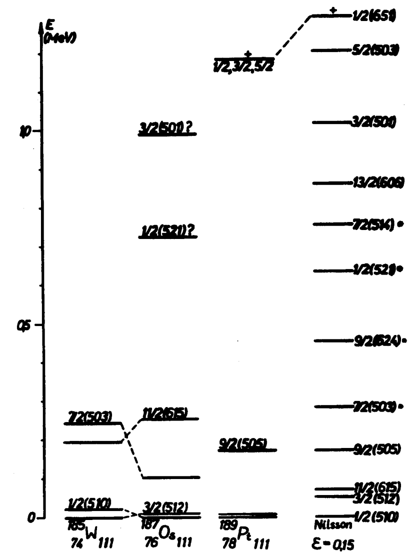

Fig. 3

the currently studied ^{189}Pt are shown in this figure. It is interesting to note that the 1161 keV positive parity (probably $1/2^+$) level, recently identified in ^{189}Pt [11,20], can also be simply explained by the Nilsson model as a 1/2 (651) state. However, this state is probably strongly mixed with

{p3/2(402), p11/2(505), n9/2(505)} 1/2,

the three-quasi-particle state, as is indicated by the low log ft (≤ 5.5) to this level[11,20].

Within this description the character of the state depopulated by the 166 keV transition is, however, not explained. Its spin-parity is probably $5/2^-$ or $7/2^-$. It is tempting to explain the 166 keV E2 transition as a crossover (I + 2 → I) transition within a rotational band built on a I = $1/2^-$ or I = $3/2^-$ single-particle state. The recent, preliminary value for the half-life of this transition[26] (0.2 - 0.3 nsec) seems to be in good agreement with this supposition. In this case the M1 or E2 (0.5 μsec) low-energy isomeric transition would be K-forbidden, which may explain its hindrance. However, the suspicious lack of a cascade de-excitation (I + 2 → I + 1) as well as any de-excitation to the members of the second band puts doubt on this simple interpretation. (The intepretation of this level as 7/2 (503) is even less justified within currently available data.)

3.2 Odd-A Ir nuclei

Our investigations[4] of the decay scheme of ^{187}Pt extend the systematics of energy levels in odd-A Ir nuclei[27-33]. Some of the established states in these nuclei are presented in the Fig. 4. More details concerning $^{189-193}Ir$ can be found in a paper[34] presented during this conference. The description of the lowest levels as members of Coriolis mixed 3/2 (402) and 1/2 (400) rotational bands has been proposed[31,35], although the $1/2^+$ level certainly also has a strong vibrational (K-2) component[16,36]. From the Nilsson model one also

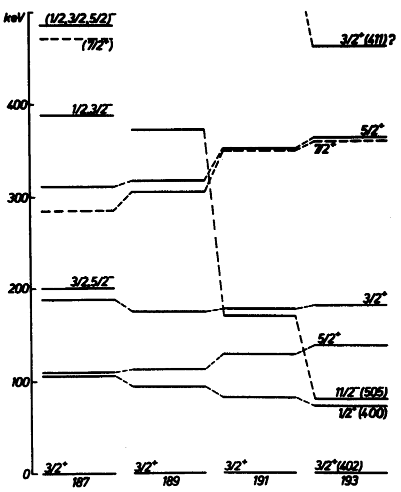

Fig. 4

expects the existence of low-lying 1/2 (541), 3/2 (532), 1/2 (660), and 3/2 (651) states. The identification in the present work of a number of negative parity states in ^{187}Ir can probably be explained by excitation to the first two mentioned orbitals.

The extension of the energy levels systematics to ^{187}Ir shows that the low-energy positive parity states follow well the trends observed in heavier Ir nuclei. Using the half-life value of the first excited state in ^{187}Ir (and also our more exact values for ^{189}Ir and ^{191}Ir) and recent multipolarity mixing determinations, we confirm the systematic change with A of the M1 and E2 transition probabilities from the $1/2^+$ to $3/2^+$ states in these nuclei[16] [see Fig. 5, based on our data and data quoted elsewhere[37-40]].

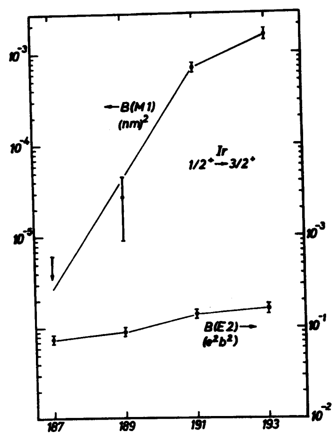

Fig. 5

The hindrance factor of the M1 part of this transition has a very high value in the case of ^{187}Ir. The mechanism of this delay may perhaps be attributed to the M1 matrix element cancellation due to Coriolis mixing, $\Delta N = 2$ mixing (expected in this region), or vibrational mixing. Detailed calculations of the mixed wave function in these nuclei are necessary in order to find if this is the reason for the systematic change of the transition probabilities from the $1/2^+$ to $3/2^+$ states and for the unusually high retardation (in comparison with the estimate of Ref. 38) of the M1 component in ^{189}Ir and ^{187}Ir (respectively, 1.1×10^5 and $\geq 5.4 \times 10^5$, S = 2).

The 155 nsec isomer in ^{187}Ir apparently has no analogue in heavier odd-mass Ir nuclei. Only one delayed transition (247 keV) was seen to be associated with this isomer, indicating that its energy is not higher than ∿ 300 keV (or that this isomer decays to another much longer-lived isomeric state). The M1 multipolarity of the delayed transition can hardly explain the existence of this isomeric state. We are searching for a low-energy transition to account for the observed half-life of the metastable state.

3.3 Isomers in ^{185}Os

The 157 keV (measured multipolarity M1 from our data and Ref. 24) transition was observed to be associated with a 0.7 μsec isomeric state in ^{185}Os. As in the case of ^{187m_2}Ir, the existence of this metastable state is difficult to understand on the basis of the observed multipolarity. The same isomer was recently discovered by the (α,yn) reaction[41].

We have evidence for a second isomeric state in this nucleus, having a half-life of about 3 μsec. The existence of this isomer is, however, only tentative at present.

4. CONCLUSIONS

We have discovered a number of isomeric states in the $185 \leq A \leq 189$ mass region. In some cases, taking advantage of supplementary information from decay studies, the Nilsson model characteristics were tentatively attributed to the observed isomeric levels.

However, supplementary experimental information or detailed theoretical calculations are necessary to account for the observed unusual retardation of some transition probabilities.

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