International Atomic Energy Agency

INDC(CCP)-394
Distr. G, ND

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

EXPERIMENTAL GROUNDS FOR NUCLEAR SHAPE ISOMERISM

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November 1995

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

Printed by the IAEA in Austria
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Abstract

Experimental data on fission isomeric states of actinide nuclei - halflives, energies, quantum numbers, decay branches and spectroscopic properties - are discussed. Quite a few results find their explanation in the framework of nuclear shape isomerism hypothesis being the in-thing for about thirty years. Others seem to be the hints to the quasiparticle nature of fission isomers. The problem could be solved by direct measurement of nuclear spin for isomeric states.

INTRODUCTION

The conception of nuclear shape isomerism was put forward by G.N.Flerov and V.A.Druin [66FLE] and V.M.Strutinsky [67STR] about thirty years ago. It was applied as a possible explanation to the phenomenon of anomalous fast spontaneous fission first observed by S.M.Polikanov and co-workers [62POL]. Nowadays there exists the double humped fission barrier model [80BJO] presenting a broad theoretical picture for a complex potential energy landscape of the actinide nuclei. The latter incorporates shape isomerism considering fission isomers to be located within the second minimum of the fission barrier. Nuclear deformation of unusial isomers was predicted to be twice of that one for the respective ground states.

On the whole it is a large difference in nuclear deformation between isomeric and ground state which stands to a physical reason of shape isomerism. It is not the case for a bulk of known nuclear isomers which differ from ground states in nuclear spin values.

It is mandatory to assess related experimental data and look into the nature (shape or quasiparticle ?) of fission isomers.

DATA ASSESSMENT

The data on 34 actinide isotopes revealing fission isomer states are listed in the Table adapted from [94FIR].

In most cases isomer level heights are measured with 10 % or lower accuracy. Only 8 values are known for spin-parity quantum numbers with 7 assignments based upon weak arguments and taken in parentheses. Last measured values are selected for halflives, but a situation is rather complex for some levels, e.g. in the case of uranium-238, where about 20 results of the isomer halflife measurement are known [as discussed in 91KUK]. 5 and 2 results are listed for intrinsic quadrupole momentum and g-factor values respectively. There are 12 double isomeric states. The higher level is considered to be a spin isomer of the lower one treated as the main member of a rotational band.

SHAPE ISOMERISM: PRO ET CONTRA

Experimental results creating a modern understanding of the problem are selected and discussed below.

A hint to a small value of 242Am fission isomer was obtained by [67FLE]. Study of 196Au(12-), 190Ir(11-) and 242Am(SF) isomeric state population didn't reveal any significant increase for the excitation function in the latter case as compared with the first two for the reactions with increasing of angular momentum transferred.

The following findings were interpreted as nuclear excitations built on the fission isomer level. Measurement of 230Th neutron induced fission cross section resulted in the observation of a resonant-like state [59GOH]. Intermediate structure in the 237Np subthreshold fission cross section was observed by [68FUB]. Finally the study of direct 239Pu(d, pf) reaction in the subthreshold region uncovered a single resonance in the fission cross section [71BAK]. Those three results were interpreted as a manifestation of vibrational, compound and mixed vibrational-compound excitations built on fission isomer.

Observation of gamma decay branch of 238U fission isomer was reported by [75RUS]. For the first time a level scheme concerning the fission isomer decay was constructed. But, as it was discussed in [91KUK], unfortunately that result has low reliability due to wrong isomer halflife value on the hands. Additionaly, observed 3.532 MeV gamma line was rejected as too high in energy when compared with about 2.5 MeV isomer level height. The latter point seems to be an example of uncorrect data handling.

Spectroscopic investigations of electrons preceding fission isomer decay were based on the charge plunger method [80MET] and made it possible to deduce the values of intrinsic quadrupole momentum for 236, 238U, 236, 239Pu fission isomers. The results being about twice of those ones for the ground states are considered to be in strong support of the shape isomerism conception. The data [79BEM] on large optical isomeric shift in 240Am fission isomer seem to go with the figures mentioned above and were announced by authors to be the first direct evidence to prominent nuclear deformation of fission isomer. But analysis of the whole data [80MET, 79BEM] carried out by [86VOR] gave them questionable status. Namely in the case of decay of laser oriented 240Am fission isomer conclusion of [79BEM] are based on the array of 13 experimental points (fission fragment anysotropy vs. laser wavelength) where one point is out for less then two standard deviations. The probability to get a random birth to such result was evaluated by [86VOR] to be about 70 % together with 8.5 chi squared parameter for 11 degrees of freedom. Moreover, if it was not the random case, an original experimental geometry immediately leads to a very sharp angular distribution of fission fragments:

$$V(\text{theta}) = 1 + a * \cos^{n}(\text{theta}) \quad \text{with } n >= 20,$$

being never observed by [79BEM].

Data on alpha and gamma decay branches of fission isomers are compiled by [92MAK]. No reliable results were uncovered in searching of alpha decay from isomeric states. Those negative figures are considered to demonstrate a large hindrance due to difference in nuclear shapes to be overcame in the course of alpha decay.

There is a number of experimental findings interpreted in support of quasiparticle origin of fission isomer phenomenon. Measurement of the excitation function for the fission isomer populated through 242Am (n, gamma)-reaction resulted in the following conclusion: 242Am fission isomer is located within the first minimum of the fission barrier, the state is normally deformed and has 4-quasiparticle nature [84VOR]. Just the same data came from studies of fission isomer excitation functions observed for 234, 236, 238U (n, n')-reactions. After the fitting of the 238U curve according to statistical model of isomer population level spin value of 5 was deduced [83DMI]. A hint to an important role of nuclear spin in isomer excitation was put forward by [93KUK] where higher fission isomer yield was measured for 241Am (n,n')-reaction as compared to those ones for (n, gamma)-reaction.

PROSPECTIVES

A bulk of data on fission isomer properties are successfully interpreted in the framework of shape isomerism hypothesis. At the same time the analysis of original papers reveals undirect nature of deduced conclusions. Due to background problems, statistical reliability, identification procedures used and other difficulties researchers have to rely upon some assumptions about fission isomer parameters under consideration. Examples of such questionable data handling are as following:

- rejecting of the observed gamma-line as too high in energy when compared with the isomer level height not being measured in the same experiment [75RUS];
- low statistical reliability of the data on fission fragment anisotropy [79BEM];
- wrong half-life value [80MET].

Each of the cases mentioned above is a subject of a specific discussion as it was done for the 238U fission isomer halflife in [91KUK].

Conclusions of experiments conducted by [84VOR, 83DMI, 93KUK] stand out of shape isomerism approach pointing to a possibility for fission isomers to manifest quasiparticle nature at the ground state deformation. But again those data doesn't seem to be sufficient to arrive at the final point. One of the possible solution of the problem is a direct measurement of fission isomer quantum numbers by complex technique using resonance ionisation spectroscopy by spin exchange pumping [92BAC].

Author is indebted to Dr.P.E. Vorotnikov for fruitful discussions and to the head of the Centre of Nuclear Structure and Reaction Data Dr.F.E. Chukreev for the data support.

TABLE. PROPERTIES OF FISSION ISOMERS
(Adapted from [94FIR])

Notation:

E(isomer) - level energy, keV;
SP - spin, parity;
T1/2 - halflife.

Uncertainties are in brackets.

#1 x = 1600-2600; y < 1000 from systematics;

#2 %SF branching ratio (BR):
(236U isomer) = 13 (6),
(238U isomer) = 5,
%SF BR = 100 for all others;

#3 intrinsic quadrupole momentum, b:
(236U isomer) = 32 (5),
(238U isomer) = 29 (3),
(236Pu isomer) = 37 (14; 8),
(239Pu isomer) = 36 (4),
(240Am isomer) = 29.0 (13);

#4 g - factor:
(237Pu isomer) = -0.45 (3),
(239Am isomer) = +0.74 (5);

#5 questionable existence

Nuclide	E(isomer)#1	SP	T1/2	Selected reference
236U#2,3	2750 (10)	(0+)	120 (2) ns	89MAK
238U#2,3	2557.6 (5)	0+	298 (18) ns	92STE
	2557.6 + y		> 1 ns	89HAB
237Np	2800 (400)		45 (5) ns	77MIG
235Pu	3000 (200)		25 (5) ns	89SOM
236Pu#3	3000	(0+)	37 (4) ps	77MET
	4000 (200)		34 (8) ns	71BRI
237Pu#4	2600		85 (15) ns	82RAF
	2900		1.1 (1) mcs	79GUN
238Pu	2400		0.6 (2) ns	74MET
	3500	(0+)	6.0 (15) ns	71BRI
239Pu#3	3100 (200)	(5/2+)	7.5 (10) mcs	79BAC
	3300	(9/2-)	2.6 (40;12) ns	80GUN
240Pu	2800	(0+)	3.7 (3) ns	71BRI
241Pu	2200		21 (3) mcs	70GAN
	2300		32 (5) ns	81GUN
242Pu	2200		3.5 (6) ns	75MET
	2200 + y		28 ns	70POL
243Pu	1700 (300)		45 (15) ns	80BJO
244Pu	x		0.40 (10) ns	74MOL
245Pu	2000 (400)		90 (30) ns	80BJO

238Pu	2400		0.6 (2) ns	74MET
	3500	(0+)	6.0 (15) ns	71BRI
237Am	2400		5 (2) ns	70POL
238Am	2500		35 (10) mcs	73FLE
239Am#4	2500 (200)	(7/2+)	163 (12) ns	72BRI
240Am#3	3000 (200)		0.94 (4) ms	71BRI
241Am	2200		1.0 (3) mcs	93KUK
242Am	2200 (80)		14.0 (10) ms	62POL
243Am	2300 (200)		5.5 (5) mcs	70POL
244Am	2800 (400)		0.90 (15) ms	72WOL
	2800 + y		6.5 mcs	69SIZ
245Am	2400 (400)		0.64 (6) mcs	72WOL
246Am	2000		73 (10) mcs	72WOL
240Cm	2000		10 (3) ps	76SLE
	3000		55 (12) ns	76SLE
241Cm	2300		15.3 (10) ns	71BRI
242Cm	1900 (200)		40 (15) ps	76SLE
	2800		0.18 (7) mcs	71BRI
243Cm	1900 (300)		42 (6) ns	80BJO
244Cm	2200		< 5 ps	69MET
	3500		> 100 ns	69MET
245Cm	2100 (300)		13.2 (18) ns	72WOL
242Bk	x		9.5 (20) ns	72WOL
	x + y		0.60 (10) mcs	72WOL
243Bk#5	2200		5 ns	72GAN
244Bk	x		0.82 (6) mcs	72GAN
245Bk	1560		2 (1) ns	72GAN

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