A MT-17 ELECTRON ACCELERATOR AND NUCLEAR ISOMERS STATES STUDY

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Abstract

On the electron accelerator with 15 MeV and 5μA bremsstrshlung beam, Sn and Ba samples had been irradiated and the isomer products of Sn117, Sn119 and Ba129 nuclei had been given. Their gamma spectra were monitored. The ratio of cross section of photoactivation reactions forming Sn117m and Sn119m was evaluated. The separation of the decay individual schemes of the two almost same half-life Ba129 isomers had been discussed. Their beta transition parameters and, then, the microscopic characteristics as spin and parity values of Cs129 levels had been assigned.

1 INTRODUCTION

The Microtron MT-17 accelerator have been put into operation since 1982 and up to now, still exploited. It has been used in both fundamental and applied nuclear physic fields. The main activities were focused on: i/ Nuclear data study (fotoreaction cross sections, photofission mass and charge distributions, isomeric cross sections ratios). ii/ Application and development of activation analysis method.

The accelerator related research results obtained during the recent years had been reported at APAC98 [1] and summarized in an other report presenting at this APAC'01 [2]. In this paper we present only some results related to the studies of nuclear isomers states during last time.

2 EXPERIMENT

2.1 About the accelerator

The Microtron MT-17 electron accelerator was made in JINT (Dubna, near Moscow) and had been transferred to Institute of Physics, Hanoi in 1982. This machine is possible to accelerate electron beam of up to 18μA and produces both:

i/ bremsstrahlung photons with $E \leq 15MeV$

ii/ fission neutrons with total out put $\approx 10^{11}$ n/s

The bremsstrahlung photons are produced in channel 56^{O} by bombarding electron beam into a tungsten (W) target:

$e \rightarrow W \rightarrow$ *bremsstrahlung*

The fission neutrons are produced in channel 0^{O} with the aid of two converts, Tungsten (W) and Uranium (U):

$e \rightarrow W \rightarrow$ *bremsstrahlung* $\rightarrow U \rightarrow$ *fission neutrons*

In present paper, Sn and Ba radioactive nuclei were the products of the irradiation of the bremsstrahlung beam of MT-17 Microtron operated at 50 kV, electron current I_e~ 5-8 μA and energy of E_e less than 15 MeV.

2.2 Target

Thin natural tin (Sn) foil of 0,07568 and natural Barium powder in the chemical form of BaO of 9,3204g and 10,2152g were used. Sn source has many isotopes such as: Sn112 (1%); Sn114 (6%); Sn115 (0.35); Sn116 (14.4%); Sn117 (7.6%); Sn118 (24.1%); Sn119 (8.6%); Sn120 (32.8%); Sn122 (4.7%) and Sn124 (5.8%). Natural Ba consists of the different isotopes such as: Ba130 (0.1%); Ba132 (0.095%); Ba134 (2.4%); Ba135 (6.5%); Ba136 (7.8%); Ba137 (11.2%) and Ba138 (71.9%).

2.3 Measurement

Gamma spectra had been followed and registered by high purity Ge plannar detector and larger (62cm3) high purity Ge one.

3 EVALUATION OF ISOMERIC CROSS-SECTION OF REACTIONS FORMING Sn117m AND Sn119m

3.1 Identification of isomers

Because the irradiated Sn samples have many isotopes and energy distribution of the bremsstrahlung beam was largely spreaderred, the different reactions such as (γ,γ'), (γ,n) and (γ,p) occur.

We had paid mainly an attention to two gamma peaks of 24keV energy of Sn119m isomer and 158 keV of Sn117m one. These two peaks were used for estimating and comparing with the reaction cross section forming two corresponded isomers. Regarding to energy the 24 keV peak has the same value of the group of X rays belong to some Indium impurities. But when measurement will be take in a day or more (approximately 10 times of decay half life of In117) all contribution can be ignored

3.2. On (γ,γ') reaction inducing Sn117m and Sn119m isomers

The mechanism of isomer activation or (γ,γ') reaction can be understood from theory of nuclear resonance fluorescence [3]. Gamma rays of energies matching the excitation energy levels of nucleus within the region of the level width are resonantly absorbed with very high

cross-section. From this excited state the nucleus can decay to ground state via other intermediate states, either directly or via the metastable level (isomer) if the excited and isomeric states have the appropriate spin and parity.

The above described (γ,γ') isomer activation must be occured with the induction of Sn117m and Sn119m isomers.

The estimation of the contribution of Sn118(γ,n)Sm117m and Sn120(γ,n)Sm119m reactions bases on: i/ The results of the experiment and calculation [4] showed that the values of σ(γ,1n) in the processes as Sn118(γ,n)Sn117m, Sn120(γ,n)Sn119m and Sn124(γ,n)Sn123m are approximately the same. ii/ The appeared in gamma spectra peaks at 158,6 keV of Sn117m and at 160,3 keV of Sn123m are in the same energetic range, so in the calculation the error of the detector efficiency can be avoid. On other side, the Sn123 isomer induced by Sn124(γ,n)Sn123m reaction is unique product and is not interfered by any other reaction channel.

So that, the ratio of the cross sections of following (γ,n) and (γ,γ') reactions were defined as:

$$\sigma(\gamma,n)Sm119m/\sigma(\gamma,\gamma')Sm119m \approx$$
$$\sigma(\gamma,n)Sm117m/\sigma(\gamma,\gamma')Sm117m = 0.15\pm0.07$$

Then, it is possible to compare the cross section of the Sn117(γ,γ')Sm117m and Sn119(γ,γ')Sm119m basing on the characteristic gamma peaks 158 keV and 24 keV in the obtained spectrum.

After correcting every necessary factors and using known formulas, it was found

$$\sigma(\gamma,\gamma')Sn117m/\sigma(\gamma,\gamma')Sn119m=0.15\pm0.08 \quad (a)$$

This values in [3] was of

$$\sigma(\gamma,\gamma')Sn117m/\sigma(\gamma,\gamma')Sn119m \approx 0.3 \quad (b)$$

The difference between two (a) and (b) experimental values may be due to the difference of the shape and maximum energies of used exiting photons spectra. It must be noted in [3] that the scattered photons of 2754 keV (Na24 gamma rays) were used to irradiate Sn sample.

Besides, the value of isomeric yield ratio in (a) showed that the cross-section of (γ,γ') reaction for exiting isomer of Sn119 is larger than that of Sn117. It could be caused by the difference between these nuclei in energy level structure.

4 Ba129 ISOMERS AND THEIR DECAY

4.1 Introduction

It has been well known the existence of two isomeric states of Ba129 nucleus which decays by electron capture (EC) and positron emission (β+) to levels in Cs129 with approximately the same half life. The complete separation of their individual decay schemes and the combination of data on beta and gamma spectra measurements will allow to determine the typical parameters of beta decay from each of Ba129 states, such as their transition energies and probabilities or comparative half-lives. Then the microscopic characteristics as spin J and parity π values of several energy levels in Cs129 will be discussed.

4.2 The separation of individual decay schemes

The separation combined energy level scheme into individual schemes could be carried out by means of a comparison of the intensities of gamma rays emitted from Ba129 radioactivity sources produced through different reactions such as (γ,n) and (p,5n) carried out by two author groups. The first group (included us) used the Ba130(γ,n)Ba129 reaction with low energy photons. Their small momentum values leads to the possibility to produce low-spin Ba129 ground state (1/2+) from ground state (0+) of Ba130 target isotope is dominat. At the same time, the second one used (p,5n) reaction. In this case, the high momentum values of protons leads to the possibility to produce high-spin Ba129m isomer became dominant.

The comparison had been done and allowed separate two gamma rays groups populating from each of both Ba129 states or two their corresponding decay schema from the combined scheme taken from [5]. The obtained results are presented in table 1.

Table 1: Cs129 energy levels populated from different Ba-129 states

Cs129 levels		Populated by		Cs129 levels		Populated by	
energy (keV)	Jπ (*)	isomer	ground states	energy (keV)	Jπ (*)	isomer	ground states
0	1/2+	no	yes	1165.0		no	yes
6.55	5/2+	yes?	yes	1208.4		yes	no
135.6	3/2+	no?	yes	1256.1		yes	yes
188.8	7/2+	yes	no	1450.8		yes	no
209.1	5/2+	yes?	yes?	1459.1		yes	no
220.8	3/2+	no	yes	1487.3		yes	no
426.8		yes	no	1609.3		no	yes
551.5		yes	no	1648.2		yes	no
554.1		no	yes	1681.4		yes	no
554.4		yes	no	1682.7		yes	no
575.6		yes	no	1700.9		no	yes
603.6		yes	no	1812.5		yes	no
648.4		yes	no	1830.5		no	yes
690.5		yes	no	1922.8		no	yes
755.3		yes	no	1940.2		yes	no
879.1		yes	no	1954.0		no	yes
969.6		yes	no	2019.0		yes	no
992.4		yes	no	2077.0		no	yes
1156.0		yes	no				

(*) taken from [5]

4.3 The parameters of beta decay

a/ Decay energies

The complete separation of their individual decay schemes and the combination of data on beta [6] and our gamma spectra measurements and of [5,6] allow to determine the typical parameters of beta decay from each of Ba129 states, such as their transition energy and probability (or comparative half-life). It is noted that the decay of Ba129 isomeric states occurs through electron capture (EC) and positron emission (β+) to levels in Cs129. Formulas for beta transitions can be modified and written as follows. In the case of i/ decay from Ba129 ground state, the maximum energy of its beta spectrum is:

$$Tm = 1411 - Ef \text{ (keV)}$$

and the transition energy of EC process is:

Q = 2433 - Ef (keV)

and ii/ decay from Ba129m isomer,

Tm = 1419,42 - Ef (keV)

Q = 2441,42 - Ef (keV)

Where, the Ef final state energies are determined by the values of the different energy levels of Cs129 in the decay scheme of Ba129 (table 1).

Using the upper formulas, the obtained values for each beta transition are presented in table 2 and 3, column 2, whereas the values with underlines have been also obtained before by beta measurements [6].

Table 2: The characteristics of beta decay from Ba129

Level energy	Decay energy (keV)		Decay probability, %		Values a	b		c	
(keV)	β+	EC	β+	EC	lgfτ	J	π	J	π
0	1411.0	2433	15	54	5,46	1/2	+	1/2	+
135.6	1275.4	2297.4	1,5	7,4	7,0	1/2 3/2		3/2	+
220.7	1190.2	2212.0	2,1	13	6,9	1/2 3/2		3/2	+
553.9	857.0	1879	0,16	3	7,8	1/2 3/2			
1164.9	246	1268	-	1,2	6,6	1/2 3/2			
1609.3	-	824	-	0,25	6,9	1/2 3/2			
1648.8	-	784	-	0,05	7,2	1/2 3/2			
1694.9	-	739	-	0,05	7,6	1/2 3/2			
1700.9	-	732	-	0,2	6,9	1/2 3/2			
1830.7	-	602	-	0,5	6,3	1/2 3/2			
1922.8	-	510	-	0,2	6,6	1/2 3/2			
1954.0	-	479	-	1,1	5,9	1/2	+	1/2	+
2078.0	-	355	-	0,002	7,3	1/2 3/2			

Table 3: The characteristics of beta decay from Ba129m

Level energy	Decay energy (keV)		Decay probability, %		Values a	b		c	
(keV)	β+	EC	β+	EC	lgfτ	J	π	J	π
6.5								5/2	+
188.9	1230.5	2252,5	-	5.2	6.5	5/2 7/2 9/2		7/2	+
209.1	1010.4	2232,4	-	4.4	6.4	5/2 7/2 9/2		5/2	+
426.5	992.9	2014,9	0.06	0.64	7.2	5/2 7/2 9/2		9/2	+
551.6	867.8	1889,8	0.05	0.9	7.1	5/2 7/2			
554.9	864.5	1886,5	0.19	3.53	6.5	5/2 7/2			
575.4	844.0	1866,0	0.04	0.87	7.0	5/2 7/2			
603.4	816.0	1838,0	0.04	0.90	7.0	5/2 7/2			
648.4	771.0	1793,0	0.01	0.54	7.2	7/2 9/2			
690.3	729.1	1751,1	0.04	0.77	7.0	7/2 9/2			
755.2	664.2	1686,2	0.02	0.87	6.9	5/2 7/2			
879.1	540.3	1562,3	0.01	0.57	7.1	5/2 7/2			
969.1	450.3	1472,3	0.01	0.6	7.0	5/2 7/2			
991.9	427.5	1449,5	-	1.8	6.5	7/2 9/2			
1156.2	263.2	1285,2	-	1.0	6.6	5/2 7/2			
1208.4	-	1233,0	-	1.5	6.5	5/2 7/2 9/2			
1255.6	-	1185,8	-	≤3	≥6.3	5/2 7/2			
1299.4	-	1142,4	-	2.2	6.3	7/2 9/2			
1450.8	-	990,6	-	2.0	6.4	7/2 9/2			
1459.1	-	982,3	-	1.7	6.7	5/2 7/2			
1487.3	-	954,1	-	0.9	6.8	5/2 7/2			
1647.9	-	793,5	-	47	4.6	9/2	+		
1681.4	-	760,0	-	5.2	5.5	9/2	+		
1682.7	-	758,7	-	1.6	6.2	5/2 7/2 9/2			
1812.5	-	629,9	-	12.4	4.9	9/2	+		
1940.4	-	501,2	-	1.6	5.6	9/2	+		
2019.1	-	422,4	-	0.5	5.9	9/2	+		

b/ LgfT values

In order to obtain the values on the decay probability of the different beta transitions, we used additionally beta measurement data from [6] for lowest levels (data with underline). For higher another levels, our results of gamma measurement and that from [5,6] were been used. Where, we have calculated the beta decay percent values basing on the balance principle for the intensity of gamma transitions coming to and out from each energy level.

The decay of Ba129m isomer, in principle, may be taken place through also 8.42 keV gamma transition. But the evidence of this gamma had not been observed in references. We can suggest that the contribution of the gamma decay channel from Ba129m state is negligibly small.

Obtained results of the relative intensities, then lgfT values of beta transitions from Ba129 and Ba129m are presented in tables 2 and 3, columns 3 and 4a, respectively.

4.4 Microscopic characteristics of Cs129 levels

The assignments of the possible microscopic characteristics such as the J spin and π parity for nuclear energy levels usually are carried out basing the measured results of the multipolarities of gamma transitions. This method had been used by the previous authors for the lowest energy levels in Cs129 structure scheme. Their results are shown in tables 2 and 3 (column 4c).

The multipolarity method usually is limited in the range of soft gamma transitions which emit internal conversion electrons with rather high probability. It is difficult to apply for hard gamma or high-lying nuclear levels. In this case the additional way basing experiment lgfT values of beta decay can be applied.

The assignments of Jπ are based on: i/ the suggestion that Ba129 ground state and Ba129m isomeric state have their spin and parity of 1/2+ and 7/2+ [6], respectively. ii/ Selection rules for beta decay and obtained lgfT values showed in tables 2 and 3.

The columns 4b of tables 2 and 3 show the obtained results assigned the J spin and π parity for Cs129 levels. Besides of new results, mainly, with high-lying levels, our assignments are in agreement with the known data [5,6,7] for the low-lying levels in the structure scheme of Cs129.

To conclusion, we hope that the results obtained in this paper will be used in combining with another information sources allow to more clarify the internal physical structure of Cs129 and its neighbor nuclei region in according to the different nuclear structure models.

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