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STUDY OF THE ISOMERIC RATIO OF $^{135m,g}_{54}$Xe IN PHOTOFISSION $^{237}_{93}$Np IN THE GIANT DIPOLE RESONANCE REGION

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Abstract. *In this work we present the results of measurement of the isomeric ratio of fission fragment $^{135}_{54}$Xe in photofission of ^{237}Np induced by bremsstrahlung in the Giant Dipole Resonance Region by the method using the inert gaseous flow. The experiments have been performed at the electron accelerator Microtron MT-25 of the Flerov laboratory of Nuclear Reaction, Joint Institute for Nuclear Research, Dubna, Russia. The results were discussed and compared with that of other authors.*

I. INTRODUCTION

The study on the angular momentum of the fission fragment provides information on the scission configuration as well as mechanism of energy dissipation, leading to better understanding of the dynamics of the fission process [1, 2]. The angular momentum presented in the initial fission fragments is dissipated at the later stages of gamma ray cascade. On the other hand the angular momentum is closely connected to the ratio of the probabilities of population of the isomeric and ground states of the fragment, so called isomeric ratio. The measurement of this ratio in nuclei formed in states with different angular momenta presents one of directions in investigating nuclear structure. This allows to obtain important information about the dependence of level density on angular momentum and the probabilities of radiation transitions between the levels. Simultaneously the measurement of the isomeric ratio in fission fragment allows to discuss about characteristics of the fission process, in part the role of different kinds of collective movements, affecting on increasing the angular momentum of fragments at the scission moment of fissioning nuclei [3, 4]. Up to now most of investigations were concentrated on the study of the isomeric ratio and the angular momentum of fission fragments in low energy fission of actinides with neutron, but the data in this study direction for photofission are very few in literature. The study led to very interesting effects such as the effects of nuclear structure and scission-point deformation on the fragment angular momentum and the correlation of fragment angular momentum with average neutron number and elemental yield [5].

In this work we present the results of the experimental study of the isomeric ratio of fragment $^{135}_{54}$Xe formed in photofission of heavy nucleus ^{237}Np induced by bremsstrahlungs in Giant Dipole Resonance Region, namely by 25 and 13.5 MeV bremsstrahlung. As $^{135}_{54}$Xe and $^{237}_{93}$Np are even-odd nuclei the data obtained may present more interesting for fission process.

II. EXPERIMENTAL

Usually the photopeaks characterizing the isomeric and ground states of a fission fragment are observed on high background of other fragments and it makes the determination of the isomeric ratio less accurate or impossible. For effective decrease of the mentioned background different techniques were applied, for example catcher foil technique [6], fission fragment transportation [7] and chemical isotope separations [8,9]. In this work as $^{135}_{54}$ Xe is a gaseous state fragment therefore for determination of its isomeric ratio we used the inert gaseous flow method described in [10] for transporting this fragment from the reaction camera to the fragment collectors. The experimental setup in this method consisted of the reaction camera with irradiated target and filter, the fragment collectors, the inert gaseous flow generator and the capillary joining these parts. The reaction camera is a cylinder with inner diameter of 40 mm diameter and height of 30 mm, with ingoing window of 25 mm diameter and outgoing window of 40 mm diameter. The fissioning targets are prepared on two aluminium foils of 0.1mm thickness placed at two sides of the reaction camera. The inert gaseous flow used was He of 2atm pressure. Under this pressure the inert gaseous flow will enter the reaction camera and carry all gaseous fragments (Xe and Kr) through the filter to the collectors. All other fission fragments produced are in solid state will be catched on the wall of the reaction camera or remain in the filter. Fission fragment $^{135}_{54}$Xe is belonging to fission chain with mass number A =135. The scheme of formation $^{135}_{53}$I and $^{135m,g}_{54}$Xe is shown in Fig.1 and the decay characteristics of $^{135m}_{54}$Xe and $^{135g}_{54}$Xe are taken from [11,12] and presented in Table 1.

Y_I – the cumulative yield of $^{135}_{53}I$; 2. Y_m, Y_g – the independent yields of $^{135m}_{54}$Xe and $^{135g}_{54}$ Xe respectively; 3. P_{12} - the coefficient of isomeric transition between $^{135m}_{54}$ Xe and $^{135g}_{54}$Xe; 4. $\beta 1$ and $\beta 2$ – the beta decay coefficients of $^{135}_{53}I$ to $^{135m}_{54}$ Xe and $^{135g}_{54}$Xe respectively.

In the experiment, two collectors were used . The first one works when the photofission process is happening, it means that this collector collects all gaseous fragments $^{135}_{54}$Xe from $^{135}_{53}$I and directly from ^{237}Np target. After the photofission stopped the second collector begins to work and it collects gaseous fragment $^{135}_{54}$Xe only from $^{135}_{53}$I.

Target preparation and irradiation.

The $^{237}_{93}$Np target was prepared by thin $^{237}_{93}$ Np layer of 0.1÷3 mg.cm^{-2} thickness on two aluminium foils of 0.1 mm thickness and placed at two sides of the reaction camera. The target was irradiated by 13.5 and 25 MeV bremsstrahlung produced by Microtron MT-25 of the Flerov Laboratory of Nuclear Reaction, JINR, Dubna. The description of this accelerator and its characteristics are presented in [13]. The average electron beam was 14-15μA. The time of fragment collecting (i.e the time of irradiation) for the first

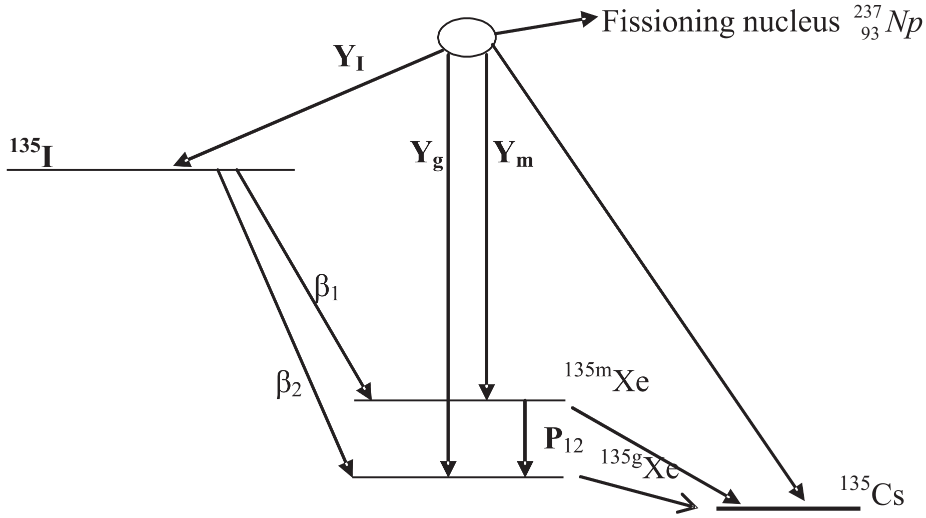

Fig. 1. Scheme of formation of ^{135}I, ^{135m,g}Xe and ^{135}Cs

Table 1. The decay characteristics of $^{135m}_{54}$Xe and $^{135g}_{54}$Xe

$^{135g}_{54}$Xe ($T_{1/2}$ = 9.104 h.)			$^{135m}_{54}$ Xe($T_{1/2}$ = 15.65 min.)		
Spin [$\hbar$]	Energy [keV]	Intensity [%]	Spin [$\hbar$]	Energy [keV]	Intensity (%)
$\frac{3}{2}^+$	158.2	0.230	$\frac{11}{2}^-$	526	81.20
	358.3	0.200			
	407.9	0.320			
	608.1	2.580			
	249.7	90.600			

collector and the time of fragment collecting for the second collector were 45 min. The time between two collections was about 10 min.

Measurement of fragment gamma spectra:

The gamma spectra of the first and the second collectors were measured with HPGe – semiconductor detector, produced by CANBERRA company. The detector has volume of 80 cm^3 and 1.8 keV energy resolution at 1332 keV gamma ray of ^{60}Co.

Determination of isomeric ratio:

The isomeric ratio was determined from different combinations of gamma spectra of the first and the second collectors for different times of cooling and measurement. In determination of the isomeric ratio of fission fragment $^{135}_{54}$Xe only two gamma ray of 249.7 and 526 keV were used due to their high intensities and it makes the results more accurate.

III. RESULTS AND DISCUSSION

As is known the gamma spectrum from fission fragment is very complicated, consisted of hundred peaks, in part photopeaks of different isotopes cover each other and simultaneously the dead time and the compton background are very high. This leads to less accurate results even for pure photopeaks of interest. In this work by using the method of inert gaseous flow all solid fragments are catched in the reaction camera, except gaseous fragments Xe and Kr, therefore the gamma spectrum is much simple, because background from other fragments is eliminated.

Table 2. The experimental results for the isomeric ratio of fragment $^{135}_{54}$Xe in photofission of ^{237}Np induced by 13.5MeV bremsstrahlung

N	t^I_{2m} [min.]	t^I_{2g} [min.]	t^I_{3m} [min.]	t^I_{3g} [min.]	ε^I_m	ε^I_g	S^I_m [Count]	S^I_g [Count]	t^{II}_{2m} [min.]	t^{II}_{3m} [min.]	ε^{II}_m	S^{II}_m [Count]	Isome Ratio IR
1	5	5	15	15	$4.22.10^{-2}$	$9.39.10^{-2}$	778	713	4.2	15	$4.22.10^{-2}$	486	1.018
2	20.5	20.5	30	30	$4.22.10^{-2}$	$9.39.10^{-2}$	568	1500	4.2	15	$4.22.10^{-2}$	486	0.821
3	5	5	15	15	$4.22.10^{-2}$	$9.39.10^{-2}$	778	713	20	30	$4.22.10^{-2}$	307	0.787
4	20.5	20.5	30	30	$4.22.10^{-2}$	$9.39.10^{-2}$	568	1500	20	30	$4.22.10^{-2}$	307	0.671
5	5	20.5	15	30	$4.22.10^{-2}$	$9.39.10^{-2}$	778	1500	4.5	15	$4.22.10^{-2}$	486	0.904
6	20.5	5	30	15	$4.22.10^{-2}$	$9.39.10^{-2}$	568	713	4.5	15	$4.22.10^{-2}$	486	0.979 $\overline{IR} = 0.863$ ± 0.103

Here: t^I_{2m} and t^I_{3m} - the cooling and measurement times for $^{135m}_{54}Xe$ in first collector; t^I_{2g} and t^I_{3g}- the cooling and measurement times for $^{135g}_{54}Xe$ in the first collector; ε^I_m and ε^I_g - the efficiencies for the isomeric and ground states in the first collector; S^I_m and S^I_g - the areas under the isomeric and ground states photopeaks in the first collector; t^{II}_{2m}, t^{II}_{3m}, ε^{II}_m and S^{II}_m - the cooling and measurement times, the efficiency and the area under the isomeric state photopeak in the second collector.

In Fig. 2 is shown a part of the spectrum photofission of $^{237}_{93}$Np induced by 25 MeV bremsstrahlung, measured for the second collector. Here the photopeaks characterizing the isomeric and ground states of $^{135}_{54}$ Xe are seen very clear. Other photopeaks appeared in the spectrum are from other isotopes of Xe and Kr. This spectrum is very simple in comparison with total spectrum of photofission and makes the data processing more simplified and higher accurate. The isomeric ratio was determined as the average value $\bar{IR}$of that calculated from different combinations of a series of gamma spectra measured for the first and the second collectors. In Table 2 is shown the results of the case of irradiation with 13.5 MeV bremsstrahlung and for 25 MeV bremsstrahlung the calculating procedure is the same. The relative error was determined by following formula:

$$\varepsilon\left(\bar{IR}\right) = \frac{\sigma\left(\bar{IR}\right)}{\bar{IR}} = \frac{\sqrt{\sum\limits_{i=1}^{n} \sigma_i^2\left(IR\right)/n}}{\bar{IR}} \quad (1)$$

Where $\sigma_i\,(IR)$ - the error of the isomeric ratio calculated for i^{-th} measurement and n – number of measurements

In Table 3 are shown the results of this work for the isomeric ratios in fragment $^{135}_{54}$ Xe and that of other authors for fragments $^{135}_{54}Xe$, $^{134}_{53}I$, $^{130}_{51}Sb$ and $^{132}_{51}Sb$ for comparison. Due to the data for the isomeric ratio of fragments in photofission of $^{237}_{93}Np$ are very few and we could not find them even in fission induced by neutron.

Table 3. The isomeric ratio of $^{135}_{54}$ Xe, $^{134}_{53}$I, $^{130}_{51}$Sb and $^{132}_{51}Sb$ in photofission of some heavy nuclei induced by bremsstrahlung

Heavy nuclei	Isomeric nuclei	Bremsstrahlung energy [MeV]	Isomeric Ratio	Reference
^{237}Np	$^{135}_{54}$ Xe	13.5	0.863 ± 0.103	This work
^{237}Np	$^{135}_{54}$ Xe	16.0	0.610 ± 0.060	[14]
^{237}Np	$^{135}_{54}$ Xe	25.0	1.410 ± 0.180	This work
^{237}Np	$^{134}_{53}I$	16.0	2.400 ± 0.200	[14]
^{238}U	$^{134}_{53}I$	16.0	0.670 ± 0.130	[14]
^{238}U	$^{135}_{54}$ Xe	16.0	0.220 ± 0.030	[14]
^{238}U	$^{130}_{51}Sb$	16.0	0.860 ± 0.150	[14]
^{238}U	$^{132}_{51}Sb$	16.0	0.790 ± 0.130	[14]

From Table 3 it is seen that our results are higher than the values of the isomeric ratio obtained in [14]. The isomeric ratio in fragment $^{135}_{54}Xe$ for 25 MeV is higher than that for 13.5 MeV bremsstrahlung. This fact can be explained with the higher excitation energy in the first case. It is also seen that in photofission induced by bremsstrahlung in the giant dipole resonance region for the same fissioning nucleus, the isomeric ratio of Z- odd fragments ($^{134}_{53}I$,$^{130}_{51}Sb$ and $^{132}_{51}Sb$) is higher than that of Z-even fragment ($^{135}_{54}Xe$). This fact may connect with the odd – even effects in fission fragment shown in [5,16].

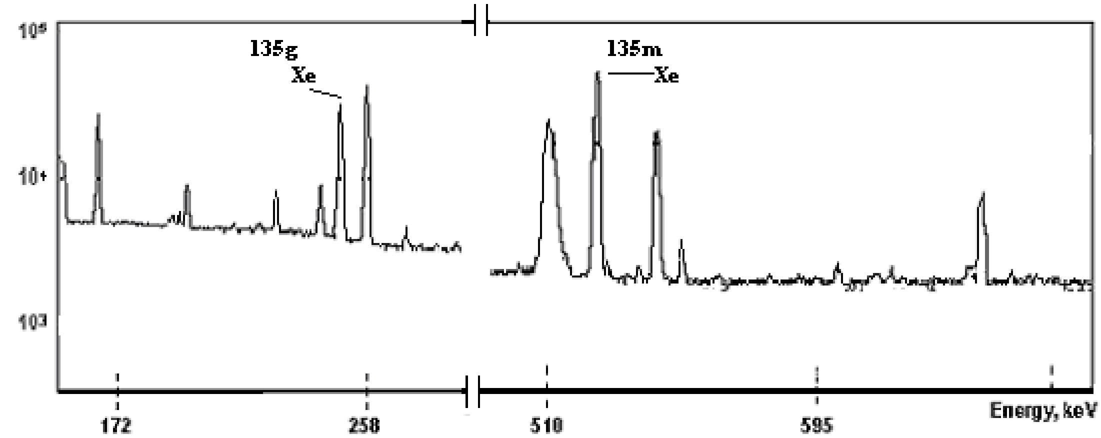

Fig. 2. Spectrum for the case of photofission of Np^{237} at 25 MeV bremsstrahlung

It is very interesting to remark that the isomeric ratio in fission fragment ${}^{135}_{54}$ Xe from photofission of ^{237}Np is much higher than that of nucleus product ${}^{135}_{54}$ Xe formed in reactions ${}^{134}_{54}Xe(\mathbf{n,}\ \gamma)\ {}^{135m,g}_{54}$Xe (IR=0.013) and ${}^{136}_{54}$Xe$(\gamma, n){}^{135m,g}_{54}$Xe (IR=0.11) [15]. This may lead to additional mechanism of increasing the isomeric ratio and the angular momentum of the nucleus at scission moment of fission fragment. Though the photofission is induced by 25 and 13.5 MeV bremsstrahlung but the main contribution carrying in the giant dipole resonance region are about 12.5 and 8.0 MeV respectively. These energies and also a part of the energy separated in the fission process lead to higher excitation isomeric ratio of fission fragments and emission of neutron from them.

This fact can be seen clearly from the following formulas:

$$E^*_{cn} = \frac{\int\limits_{Bf}^{Ee} E\sigma\left(\gamma, t\right)\phi\left(E_e, E\right)dE}{\int\limits_{Bf}^{Ee} \sigma\left(\gamma, f\right)\phi\left(E_e, E\right)dE} \tag{2}$$

$$E^*_f = E^*_{cn} + Q - TKE' \tag{3}$$

In formulas (2) and (3) B$_f$ – the fission barrier; $\sigma\left(\gamma, f\right)$- the photofission cross-section; $\phi\left(E_e, E\right)$ - the bremsstrahlung spectrum; E$_e$ – the electron energy; Q – the mass defect difference before and after reaction; TKE' – the total kinetic energy of fission fragments; E^*_{cn}- the mean excitation energy of compound nuclei and E^*_f- the total excitation energy of fragments and higher isomeric ratio.

Further, it is assumed that the total excitation energy of fragments is proportionally divided between their atomic masses. From formula (3), one can see that a part of the energy, namely Q-TKE' separated in the fission process leads to higher excitation energy of fragment and higher isomeric ratio.

IV. CONCLUSION

In conclusion we would like to say that the study on the isomeric ratio of fission fragment ${}^{135}_{54}$ Xe in photofission of ^{237}Np in the giant dipole resonance region is one of directions for investigation of nuclear structure. This provides important information on the nuclear level density, the nuclear structure effect, the role of collective and intrinsic degrees of freedom and the effect of fragment deformation. The choice of ${}^{135}_{54}Xe$was due to the condition that this nucleus can be formed not only directly from fission but also in such single reaction (n, γ) and (γ, n). The mechanism of these reactions are well-known and the angular momentum of absorpted γ quantum and energy of projectile neutron are fixed. Therefore in the case of this reaction it is possible to perform the detail calculation of change on the angular momentum of the nucleus at population of the isomeric and ground states and then from the isomeric ratio are obtained the parameters of level density, which can be used for theoretical calculation of the isomeric ratio in photofission fragment ${}^{135}_{54}$Xe. The results of this work could contribute to the nuclear data.

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