ISOMER YIELD RATIOS OF FISSION FRAGMENTS ^{133}Te, ^{134}I, ^{135}Xe IN (γ, *f*), (γ, *nf*) REACTIONS ON ^{235}U

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Abstract

Isomeric yield ratios of fission fragments ^{133}Te, ^{134}I, ^{135}Xe in (γ, f), (γ, nf) reactions on ^{235}U were measured. The contributions to the isomeric yields from nuclei of isobaric chains due to β-decay were taken into consideration. The sample was irradiated by bremsstrahlung of microtron M-30 (Institute of Electron Physics, Uzhgorod, Ukraine) with 17 MeV end point energy. The average angular momenta of the primary fragments were determined with the use of these data. The codes TALYS 1.4 and EMPIRE 3.2 were applied in the calculations. The effect of different expressions for the radiative strength functions and nuclear level densities on average angular momenta was studied.

1. Introduction

It is well known that studies of angular momenta of fission fragments provide useful information on the scission configuration and consequently lead to a better understanding of the fission process. In the past, several experimental techniques, as e.g., measurements of the anisotropy and number of emitted gamma rays, ground state band populations in even-even fission products, and isomeric yield ratios, have been used to obtain information on primary angular momenta of fission fragments produced in different fissioning systems. It has been well established that in fission most of the fragments are formed with much higher angular momenta than those of the fissioning nuclei.

The most popular method for obtaining information on the average angular momenta of fission fragments is measuring the isomeric ratios $R = \sigma_m/\sigma_{g,,}$ where σ_m, σ_g are the cross sections of the production of metastable and ground states of the fission fragment. Nuclei close to magic numbers with A ~ 90, Z ~ 40 and A ~ 132, Z ~ 50 are the easiest to use in investigations. Isomeric and ground states are formed in these nuclei due to subshells with substantially different quantum numbers ($p_{1/2}$, $g_{9/2}$) to N = 50; $s_{1/2}$, $d_{3/2}$, $h_{11/2}$ near N = 82. The lifetimes of these nuclei are rather prolonged for radiochemical separation [1–3].

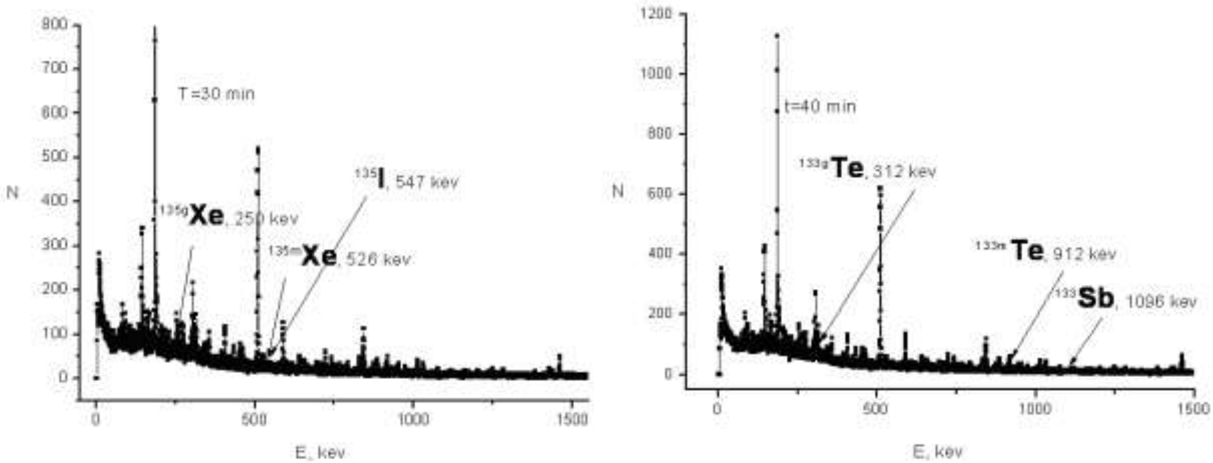
It should be noted that most of the information on $R = \sigma_m/\sigma_g$ was obtained via (n, *f*) fission reaction with thermal neutrons, and even–even nuclei were mainly studied. Most of the information was obtained earlier for γ-energies below 10 MeV, when on ^{235}U is possible only (γ, *f*) reaction. In this contribution we present measurements of isomer ratios of photofission fragments for the bremsstrahlung with 17 MeV end point energy when possible also (γ, *nf*) reactions. The average angular momenta of the primary fragments were determined with the use of these data.

2. Experimental method and results

Isomeric yield ratios were measured by irradiation of uranium sample and identification of the radioactive products. Uranium sample with enrichment 90% of ^{235}U isotope (^{238}U — 10%) was used for measurements. The sample had a weight around 0.5gramm. The measurement of isomeric yield ratios in (γ, f)-reactions was done by using the electron beams extracted from the M-30 microtron of the Laboratory of Photonuclear Reactions at IEP, Uzhgorod. This electron beam was source of the bremsstrahlung photons. A cooled tantalum disk, 2-mm thick, served as a bremsstrahlung producing target for the beam. Exposure to bremsstrahlung was performed for the end point energy: 17 MeV. The mean electron current was around 3μA. The distance from bremsstrahlung producing target to samples was 9 cm.

After irradiation the studied samples were transferred to a separate laboratory. In the laboratory a spectroscopic system was equipped. The γ -spectra of the reaction products were measured by this system, consisting of HPGe detectors made by CANBERRA and ORTEC, amplifier 2024 and multichannel analyzer 8192, connected to computer for data processing. The detectors have energy resolution 2 keV for the 1332-keV γ -line of ^{60}Co and detection efficiency of 30% in comparison with a 3 in. × 3 in. NaI(Tl)-detector.

Typical experimental spectrums of ^{235}U photofission products are shown in Fig. 1.



(*a*) (*b*)

Fig. 1. Typical spectrums of ^{235}U photofission products: (*a*) ^{135}Xe, (*b*) ^{134}I.

An adaptation of the experimental spectra was done using the Winspectrum program [4]. This program permits the user to write the spectra in a defined time periods. Therefore, enabling the identification of the isotope from the energies of the γ -rays and the half-lives.

The experimental values of isomeric yield ratios were calculated taking into account the contributions from β-decay of isobaric chains (detailed description of these calculations can be found in [5]).

Determined isomeric yield ratios $R_{\exp} = Y_m / Y_g$ are presented in Table 1.

Table 1. Isomeric yield ratios $R = Y_m / Y_g$ for fission fragments of ^{235}U(γ,*f*) for $E_{\gamma,\text{end}} = 9.6$ MeV and 17 MeV.

Isomeric pair	$\mathrm{R_{exp}} = Y_m / Y_g$	
	17.0 MeV	9.6 MeV
^{133m,g}Te	2.8(7)	2.3(3)
^{134m,g}I	2,8(6)	0.49(5)
^{135m,g}Xe	0.15(3)	0.14(1)

For the comparison, Table 1 also presents experimental values of the isomeric yield ratios for the irradiation of ^{235}U by bremsstrahlung with end point energy $E_{\gamma,\text{end}} = 9.6$ MeV [6]. Discrepancy is observed between the experimental data for ^{134m,g}I for bremsstralung with 17 MeV and 9.6 MeV end point energies. It seems possible that it is related with opening (γ, nf)-fission channel for bremsstralung with 17 MeV end point energies.

3. Theoretical approach of the obtained results

The experimental values of $R_{\text{exp}} = Y_m / Y_g$ were used to determine the angular momentum distributions $P(J)$ and average angular momenta $\bar{J}$ of fission fragments. The following expression for the angular momentum distributions was adopted

$$P(J) = (2J+1)exp(-J(J+1)/2(\sigma+\lambda)^2)/ f_{norm}(\sigma,\lambda), \tag{1}$$

where $f_{norm}(\sigma,\lambda)$ is normalization factor which is found from condition $\int P(J)dJ = 1$, σ - cut-of parameter of spin distribution defined by the Fermi gas model ($\sigma^2 = 0.0194\, A^{5/3} T$, $T = \sqrt{U/a}$, $a = A/10$ MeV^{-1}, $U = 0.75 S_n$).

The parameter λ was found from fitting values of the calculated isomeric ratios to experimental values. Like in Huizenga-Vandenbosh method [7,8], we supposed that gamma-cascades populate ground- and isomer- states just after neutron emission when excitation energy lower than neutron separation energy. So, theoretical values of the isomeric ratios were calculated by the formula

$$R_{th} = \sum_J \int_{\Delta E} \sigma_m(E^*,J)dE^* P(J) / \sum_J \int_{\Delta E} \sigma_g(E^*,J)dE^* P(J) \tag{2}$$

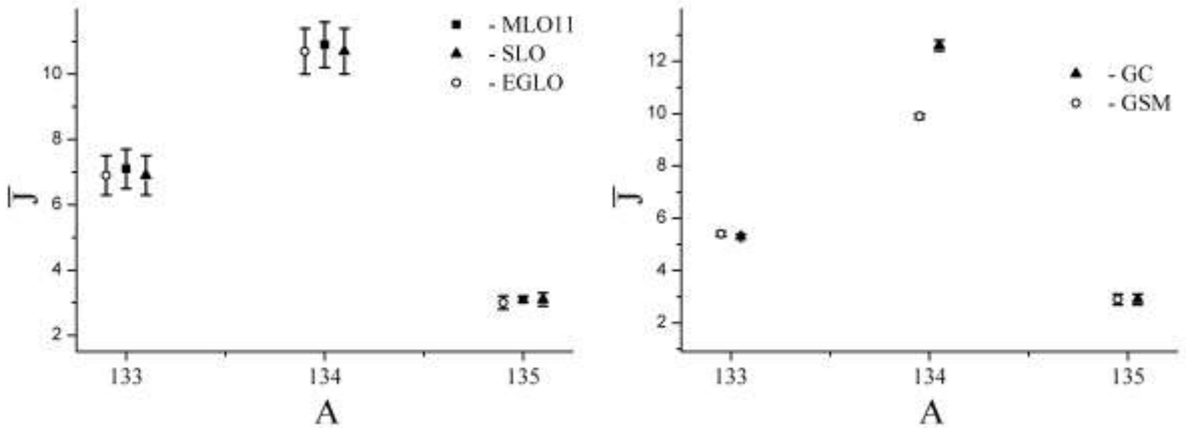
with excitation energy E^* within interval $\Delta E = 0.5 S_n \div S_n$ MeV.

The cross sections σ_m, σ_g were calculated within codes of the EMPIRE 3.2 [9] and TALYS 1.4 [10].

The average angular momenta of fission fragments $\bar{J}$ (ħ) is obtained by expressions:

$$\bar{J} = \sum_J JP(J) / \sum_J P(J). \tag{3}$$

The values of $\bar{J}$ derived from the experimental values of the isomeric ratios R_{exp} for different fragments are presented on Fig. 2. Here the uncertainties of $\bar{J}$ were defined from the uncertainties of R_{exp}. Calculations were performed with different forms of radiative strength functions (RSF) [9,11,12] and nuclear level densities (NLD) [10,11]. All other input parameters were taken by default for the codes. For clear representation, the values $\bar{J}$ are scattered on Fig. 2 for given nuclide and different models.



(*a*) (*b*)

Fig. 2. The average angular momentum $\bar{J}$ for nuclei ^{133}Te, ^{134}I, ^{135}Xe: (*a*) – calculation results for the EMPIRE 3.2 [9] code with different RSF (SLO, MLO1, EGLO, see [11,12] for details); (*b*) – results within the TALYS 1.4 code [10] with different forms of NLD(GC, GSM, see [11] for details).

It can be seen, that average angular momentum mainly depends on nuclear level density.

CONCLUSIONS

Isomeric yield ratios of fission fragments ^{133}Te, ^{134}I, ^{135}Xe have been measured in (γ, f), (γ, nf) reactions on ^{235}U for bremsstrahlung with the end point energy 17 MeV.

Average angular momenta of fission fragments ^{133}Te, ^{134}I, ^{135}Xe have been measured by using experimental values of isomeric yield ratios. These calculations were performed using EMPIRE 3.2 and TALYS 1.4 codes. The different expressions for radiative strength functions and nuclear level densities were applied.

It is demonstrated that the shapes of radiative strength functions have a little impact on the average angular momenta that are mainly effected by nuclear level densities.

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