PHOTOEXCITATION OF THE $^{11}/_{2}^{-}$ ISOMERIC STATE OF THE ^{129}TE ISOTOPE IN THE (γ,n) REACTIONS

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Dependence of isomeric ratios on the energy of gammas in the reaction ^{130}Te(γ,n)^{129m,g}Te ^{g}Te in the dipole resonance energie range have been investigated. Obtained experimental results have been compared with TALYS-1.0 calculations.

Key words: photonuclear reactions, isomeric ratios, cross-section.

Photonuclear reactions in the energy region from the particle emission threshold up to the energies higher then Giant Dipole Resonance (GDR) are the important source of information for basic nuclear physic and nuclear astrophysics. One of the directions is the investigation of the GDR decay features with the determination of the possibilities of the daughter nuclei formation in the selected quantum states. These studies are more effective and precise if daughter nuclei have isomeric levels with half-lives long enough to separate in time the processes of irradiation and measurement to provide satisfactory background conditions [1].

The aim of this work is to study the isomeric ratio (IR) (the ratio between the yields of the metastable Y_m and ground Y_g states population $d=Y_m/Y_g$) in the ^{130}Te(γ,n)^{129m,g}Te reaction.

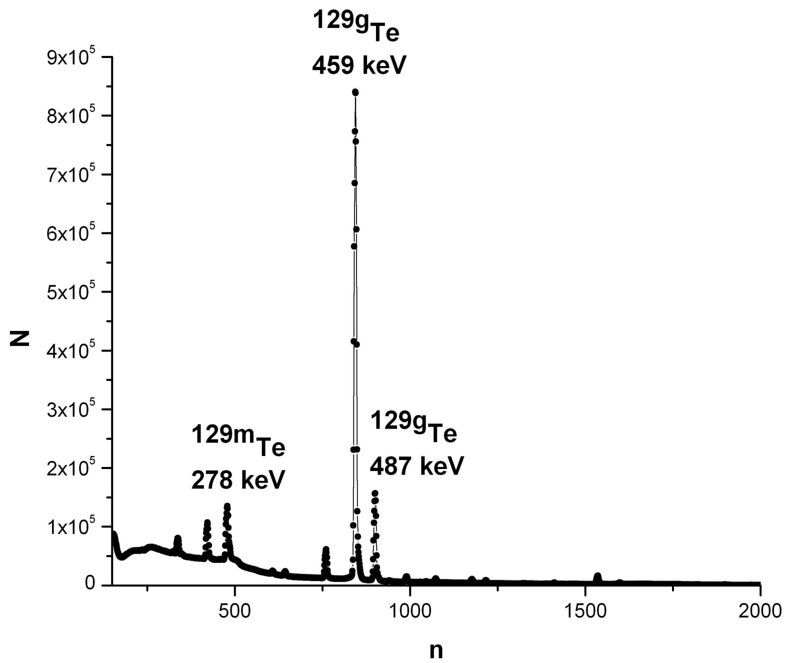
Isomeric sates in all even-odd daughter nuclei from (γ,n) reactions on Te isotopes have spin-parity $J_m^{\pi}=11/2^{-}$. Here, isomeric single quasiparticle states $J_m^{\pi}=11/2^{-}$ are formed by $1h_{11/2}$ shell and ground states – by $2d_{3/2}$, $2p_{1/2}$ shells. After E1-gamma absorption even-even target nuclei have spin-parity equal to 1^{-}. It is obvious, that having same initial conditions the behavior of isomeric ratios with the change of mass number A will depend on the change of activation levels structure and reaction mechanism.

Isomeric and ground states population yields were carried out using the Bremsstrahlung beam of the M-30 microtron at the Department of Photonuclear Processes IEP of NAS of Ukraine. Main features of the microtron are described in Ref. [2]. Energy change of the accelerated electrons in the microtron was done in two ways: in wide range – by the change of waveguides i.e. the change of the orbits; within the limits of the waveguide – by the change of the magnetic field. A 0.5 mm thick tantalum disk was used as bremsstrahlung target. The mean current of beam electrons was 5 μA and was controlled by the secondary emission monitor. Energy of accelerated electrons was determined by nuclear magnetic resonance method with measurements of the intensity of the magnetic field inside the accelerator. Glassy tellurium oxide TeO_2 samples with diameter of 25 mm and 8-10 g mass were used as the targets.

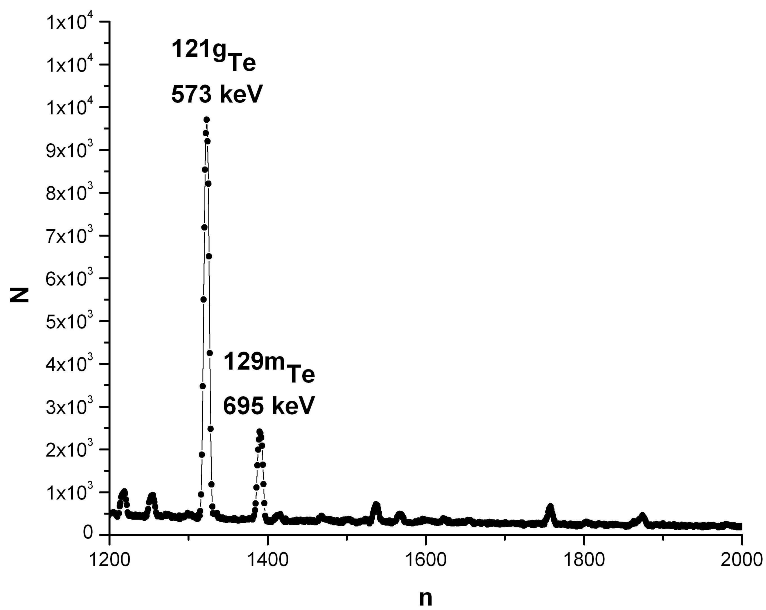
Gamma spectrum of the irradiated targets were measured by the HPGe-detector with 175 cm^3 volume and 3 keV energy resolution fore the 1332 keV cobalt-60 γ-line. The time of irradiation was 2 hours.

Investigations of the isomeric ratio dependence on the maximum Bremsstrahlung spectra energy were carried out in the energy region 8 - 18 MeV with the step ΔE = 0:5 MeV. The measurements of the isomeric ratios in every energy point were divided into two stages. After the irradiation and cooling during 2-3 hours (to reduce the dead time of the registering device) the measurements of the ^{129g}Te ground state were carried out. Then, after 4 days measurements were renewed for the long term observation of ^{129m}Te metastable state decay. That helped us to get rid of interfering influence of the E_{γ}=700 keV line from ^{119}Te decay.

A sections of the experimental gamma-spectrum from irradiated with $E_{\gamma max}$=16 MeV for 2 hours tellurium target is shown on Fig. 1. Here, *n* is the number of an analyzer channel, and *N* is the number of pulses in this channel. First spectra (Fig. 1a) was obtained after 2 hours of cooling and 90 min measuring, second (Fig. 2a) - t_{cool}=6 days, t_{meas}=20 hours.



a)



b)

Fig. 1. A sections of the experimental gamma-spectrum from irradiated tellurium target.

Following spectroscopic characteristics of the ^{129}Te: the spin parity J_{π} of the ground and isomeric states, the half-life periods $T_{1/2}$ of those states, the energy of the registered gamma-transition E_{γ} and the (γ,n)-reaction threshold *Bn* for the parent nucleus – were taken from Ref [3, 4] (see Table).

Table

Spectroscopic characteristics of nuclei ^{129}Te

	J_π	B_n, MeV	$T_{1/2}$	E_{iso}	E_γ
^{129m}Te	$^{11}/_2{}^-$	-	33.6 days	105 keV	696 keV
^{129g}Te	$^{1}/_2{}^+$	8.4	69.6 min	-	459 keV

Branching coefficient p in the ^{129m}Te decay is equal to zero, thus the isomeric ratio can be defined as the ratio between independent yields Y_m and Y_g:

$$d = Y_m / Y_g = C \frac{N_m}{N_g} \cdot \frac{\lambda_m \varphi_g f_g}{\lambda_g \varphi_m f_m} \qquad (1)$$

$\varphi_{m,g} = \xi_{m,g}\ k_{m,g}\ \alpha_{m,g}$ Here, $\xi_{m,g}$ – the photoeffectivity of photons registration from isomer and ground states decay, $k_{m,g}$ – the target's self-absorption coefficients of the analytical lines; $\alpha_{m,g}$ – the intensities of analytical gamma-lines. C = C1·C2 – coefficient for taking into account the pulses superposition and registration errors, $N_{m,g}$ – the numbers of pulses in the photopeaks of the isomeric and ground states; $f_{m,g}$ – time-dependent function:

$$f_{m,g} = [1 - \exp(-\lambda_{m,g} t_{irr})] \cdot \exp(-\lambda_{m,g} t_{irr}) \cdot [1 - \exp(-\lambda_{m,g} t_{meas})]$$

Here, $\lambda_{m,g}$ – the decay constants, t_{irr}, t_{cool}, t_{meas} – times of irradiation, cooling and measurement.

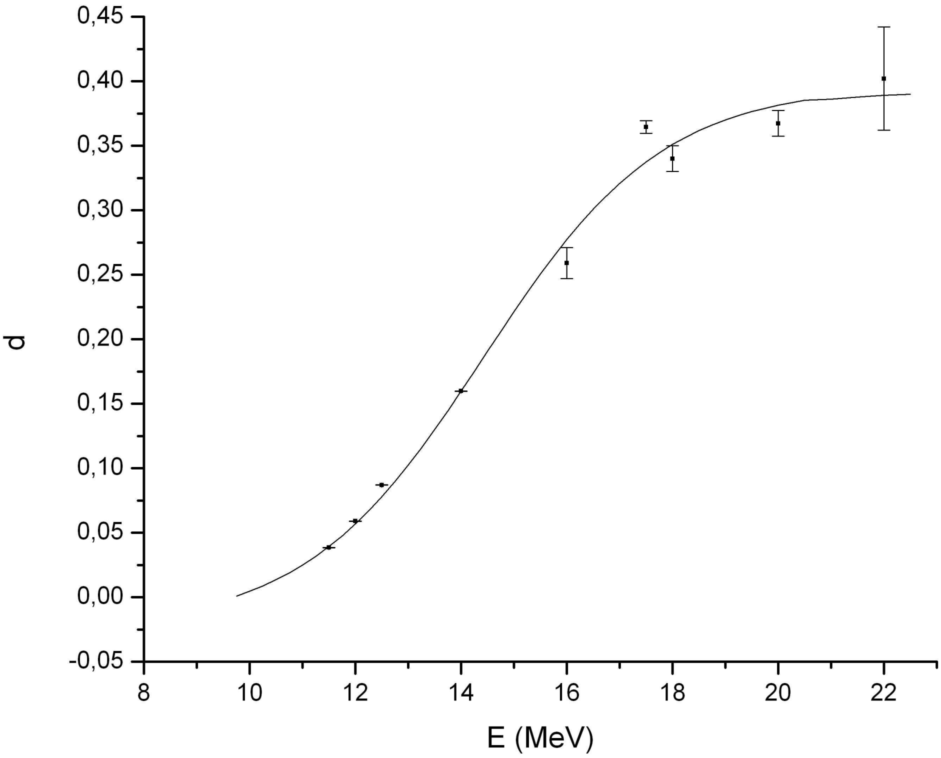


Fig. 2. Experimental isomeric ratios for the ^{130}Te(γ,n)^{129m}Te reaction.

Obtained experimental isomeric yield ratios $d=Y_m/Y_g$ for the reaction ^{130}Te(γ,n)^{129m,g}Te are plotted as dots in the Fig. 2.

The solid curve in the Fig. 2 demonstrates the results of experimental data approximation by the least-square method with Boltzmann curve

$$d = A + (B - A)/[1 + \exp(\frac{E - E_0}{\Delta E})] \qquad (2)$$

Here, A, B, E_0, and ΔE_1 are fitting parameters. The best agreement was reached with the following parameter values: A=0.3966±0.0062, B=–0.0242±0.01113, E_0=14.4278±0.1088, ΔE_1=1.6949±0.11824.

It can be seen from the analyses of the low-lying levels in the ^{129}Te nuclei that state with E = 760.0 keV and $J^{\pi}={}^{7}/_{2}^{-}$ is the most probable candidate for the activation level. Isomeric level can be feed from this state with pure E2 transition. Thus, evaluated effective threshold of the ^{130}Te(γ,n)^{129m}Te reaction will be near ~9.5 MeV.

Obtained experimental values of the isomeric ratio (solid curve in Fig. 2) together with the values for the total cross-section of the (γ,n) reactions on ^{130}Te taken from the literature [5, 6] allowed us to calculate the cross-section of the^{130}Te(γ,n)^{129m}Te reaction (dots in Fig. 3). This a single-peak curve with maximum σ = 97.9±5.0 mb at the 15.0 MeV energy. Solid line in Fig. 3 represents the results of approximation by the Lorenz curve:

$$\sigma(E) = \sigma_0 \frac{\Gamma^2 E^2}{(E^2 - E_0^2)^2 + \Gamma_0^2 E^2} \quad (3)$$

Best agreement was reached with following parameters: σ_0=98.0±1.4 mb, E_0=15.18±0.03 MeV, Γ_0=3.49±0.08 MeV.

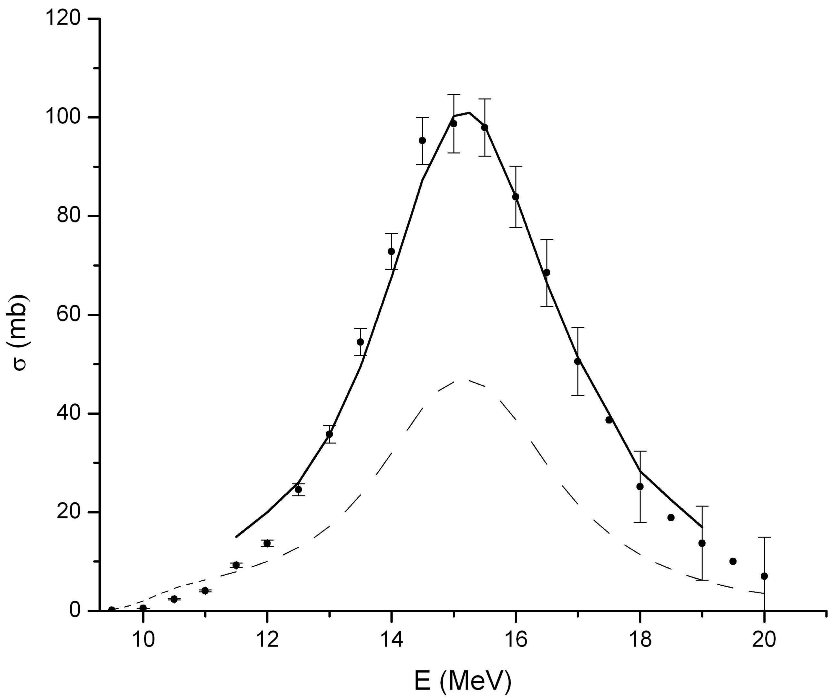


Fig. 3. The cross-section of the metastable state in the ^{130}Te(γ,n)^{129m}Te reaction.

Results of the ^{130}Te(γ,n)^{129m}Te reaction cross-section calculation done with TALYS-1.0 code are plotted in Fig. 3 with a chain line. The followed calculation scheme was used: target nucleus (Z_i, N_i) with spin-parity (J_i, π_i) absorbs incident photon with the energy E_γ. After that the compound state with all possible spin-parities combination (J_c, π_c) is formed. Total photoabsorption cross-section was calculated. The decay of the excited nucleus was treated in the framework of two different mechanisms: preequilibrium and statistical. In our case the percentage of the preequilibrium processes was changing from zero at the energy E_γ=10 MeV to 6.8% (E_γ=15 MeV) and to the 19% (E_γ=20 MeV). Hauser-Feschbach method [8] was used for statistical part of the calculation. Neutron emission with the population of the particular levels in the daughter nucleus was calculated with transmission coefficients T_l from the optical model. Energies and spectroscopic features of the nuclear levels up to the 3 MeV excitation energy were taken from the RIPL-3 data base. For the energies higher then 3 MeV energy spectra was treated as continuous and was divided into 50 energy bins. For the calculations of the decay into the continuous spectra region effective (weighted) transmission coefficient was used. Levels density were calculated with two different models: back-shifted Fermi-gas model [9] and combinatorial model based on the Skyrme-Hartri-Fock-Bogoljubov deformed nucleus model [10]. The last one takes into account the parity dependence. Calculation with both approaches for levels density determination gave almost the same results. Calculated curve is drawn in the Fig.3 with a chain line. It can be seen the discrepancy between calculated and experimental values exist. Possible reason of this disagreement can be found in underestimation of the preequilibrium processes role.

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ВИВЧЕННЯ ФОТОЗБУДЖЕННЯ ІЗОМЕРНОГО СТАНУ $^{11}/_{2}^{-}$ ІЗОТОПУ ^{129}Te В РЕАКЦІЇ (γ,n)

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В області енергій гігантського дипольного резонансу досліджено залежність ізомерних відношень виходів від енергії гамма-квантів в реакції ^{130}Te(γ,n)^{129m,g}Te. Одержані експериментальні результати порівнюються з розрахунками проведеними за допомогою програмного пакета TALYS-1.0.

Ключові слова: фотоядерні реакції, ізомерні відношення, переріз.

ИЗУЧЕНИЕ ФОТОВОЗБУЖДЕНИЯ ИЗОМЕРНОГО СОСТОЯНИЯ $^{11}/_{2}^{-}$ ИЗОТОПА ^{129}Te В РЕАКЦИИ (γ,n)

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В области энергий гигантского дипольного резонанса исследовано зависимость изомерных отношений выходов от энергии гамма-квантов в реакции ^{130}Te(γ,n)^{129m,g}Te. Полученные экспериментальные результаты сравниваются с расчетами, проведёнными с помощью программного пакета TALYS-1.0.

Ключевые слова: фотоядерные реакции, изомерные отношения, сечение.