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Research Article

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Excitation of Isomeric States in Reactions (γ,n) and (n,2n) on ^{113}In NUCLEUS

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Abstract The isomeric yield ratios of (γ, n) and (n, 2n) -reactions on nuclei ^{113}In have been measured by the induced radioactivity method. Energy dependence of isomeric yield ratios of the photonuclear reaction $^{113}In(\gamma,n)^{112m,g}In$ in the 12-35 MeV energy range is investigated.

Keywords Isomeric yield ratio, Photonuclear reaction, $^{113}In(\gamma,n)^{112m,g}In$, $^{113}In(n,2n)^{112m,g}In$ Activation method, neutron generator, HPGe detector

Introduction

The study of isomeric ratios allows one to obtain information about the mechanism of the reaction, in particular, the moment of inertia of the nucleus, the spin dependence of the density of levels, and the character of the transitions between highly excited nuclear states [1].

In the present paper, the energy dependence of the isomeric ratio of the yields of (γ,n)-type reactions on the ^{113}In nucleus in the energy range 12-35 MeV in 1 MeV steps was studied by the induced-activity method. The isomeric ratio of the reaction cross sections of type (n,2n) on the ^{113}In nucleus at the neutron energy E_n = 14 MeV has also been studied.

Experimental Procedure

The experiments were carried out on a high-current betatron SB-50 of the National University of Uzbekistan and at the NG-150 neutron generator of the Institute for Nuclear Physics (Uzbek Academy of Sciences). The experiments aimed at studying photonuclear reactions were performed in a bremsstrahlung photon beam from the SB-50 in the energy range of 12–35 MeV with a step of 1 MeV. For a target, use was made of disks from chemically pure metallic indium that were 15 mm in diameter and 1 to 3 g in mass. The target-irradiation time was 0.5 to 3 h, depending on the endpoint energy of the bremsstrahlung spectrum. In order to increase the dose power, the irradiation was performed within the accelerating chamber of the SB-50 high-current betatron at a distance of 12 cm tungsten braking target, where the sample under study placed in special container was transported by a K5-2A pneumatic-rabbit facility. The time of sample transportation to the irradiation locus with the aid of this facility was about 4 s [6]. Monitoring of the neutron flux was carried out with a plate of aluminum of natural isotope composition, which were irradiated along with the targets.

The induced γ-activity of the targets was measured with a Canberra gamma spectrometer consisting of a germanium detector HPGe (with a relative efficiency of 15%, a resolution for the ^{60}Co 1332 keV line of 1.8 keV), a DSA 1000 digital analyzer, and a personal computer with a Genie software package 2000 for the collection and processing of gamma spectra. Gamma-spectra of the targets began to be measured after a pause of 2-50 min and were measured for 3-120 min. The gamma-ray spectrum of the (n, 2n) reaction at the ^{113}In nucleus is shown in Fig. 1.

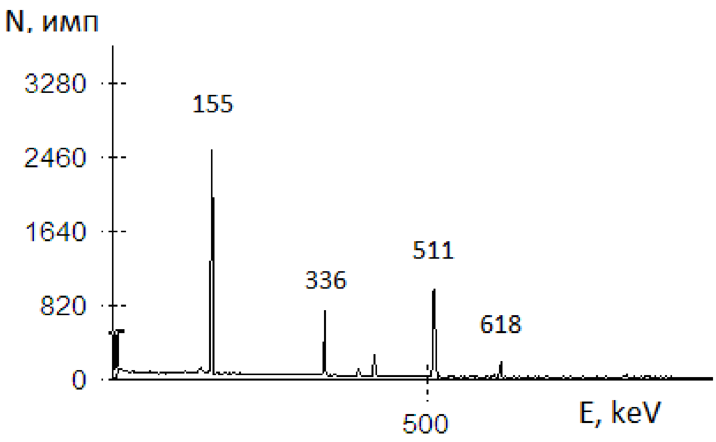

Figure 1: The spectrum of irradiated In at an energy En = 14 MeV

The population of the isomeric and the ground-state level was identified by respective gamma lines. The spectroscopic features that characterize the nuclei arising as products of the relevant nuclearreaction and that are necessary for processing the measurement results were borrowed in [2, 3] and are presented in Table 1, where I^{π} stands for the spin parity of a level, $T_{1/2}$ is the half-life of the nucleus in question, I_{γ} is the intensity of gamma rays from decay through a channel characterized by a given energy $E_{\gamma,dec}$, and p is the gamma-transition branching fraction.

Table 1: Spectroscopic properties of nuclei arising as products of the reactions (γ,n) and (n, 2n) on the ^{113}In nucleus

Product nucleus	I^{π}	$T_{1/2}$	$E_{\gamma\ dec}$, keV	I_{γ}, %	p
^{112m}In	4^{+}	20.7 min	155.4	11.2	1
^{112g}In	1^{+}	14.4 min	606.4	1.19	-
			618.2	5.29	

The isomeric cross-section ratios σ_m/σ_g were determined in the case of the reaction ^{113}In(n,2n)^{111m,g}In. In order to obtain the absolute values of the cross sections for the ground state and for the isomeric state, use was made of methods based comparing the yields of the reaction understudy and the monitoring reaction. The reaction ^{27}Al(n,α) ^{24}Na($T_{1/2}$ =15h, E_{γ} = 1368 keV), whose cross section σ_m was 114 ± 6 mb at E_n =14.6 ±0.3 MeV [4], was taken for a monitoring reaction.

Results and Discussions

The experimental results on the isomeric ratios of the yields of the (γ,n) and (n,2n) reactions on the ^{113}In nucleus are shown in Fig. 2 and in Table. 1 and 3. In Fig. 2 shows the dependences of the isomeric ratios of the yields η ($E_{\gamma max}$) = Y_m / (Y_m + Y_g) of the reaction ^{113}In (γ, n)$^{112m,\ g}$In on the maximum bremsstrahlung energy. The errors in the experimental values of η (Eγmax) for each maximum bremsstrahlung energy $E_{\gamma max}$ are due to the statistics of the counts in photopics and the errors in determining the efficiency of the detector. Taking into account a significant increase in statistical errors, measurements of reaction yields in the immediate vicinity of the photonuclear reaction threshold have not been carried out. As can be seen from Fig. 2, with increasing energy, the value of η ($E_{\gamma max}$) decreases and leaves on the plateau. The energy dependence of the isomeric ratios of the η ($E_{\gamma max}$) yields of the reaction ^{113}In (γ,n)^{112m,g}In in the energy range 26-35 MeV was obtained for the first time. Our results for the photonuclear reaction ^{113}In(γ,n)^{112m,g}In in the energy range 18-30 MeV agree within the measurement error with the data of [5, 6, 7, 8] (see Table 2). The values of the isomeric output ratios obtained in [9] are slightly higher than those of other studies. It is possible that at high energies the isomeric ratio increases. One of the possible mechanisms leading to an increase in the values of isomeric ratios for the investigated nuclei is the contribution of direct processes, the fraction of which in the region above the giant resonance increases.

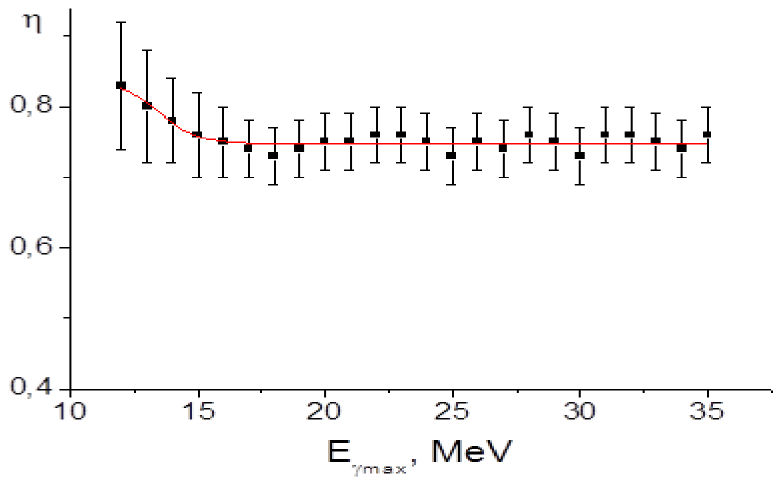

Figure 2: The isomeric yield ratios for the $^{113}In(\gamma,n)^{112m,g}In$ reaction as a function of the incident bremsstrahlung energy

Table 2: The isomer ratios of the outputs η of the reaction of the type (γ, n) on the nucleus ^{113}In

$E_{\gamma max}$,MeV	*η*	References
18	0,72±0,04	[5]
20	0,75±0,04	This work
30	0,8±0,1	[6]
30	0,69±0,06	[7]
35	0,75±0,04	This work
43	0,75±0,03	[8]
50	0,805±0,006	[9]
60	0,823±0,006	[9]
70	0,840±0,006	[9]

To obtain absolute values of the reaction cross sections, the method of comparing the yields and cross sections of the investigated and monitored reaction was used [10]. The ^{115}In (γ, n) ^{114}In reaction was used as a monitor reaction, and its excitation function was well studied. For the ^{115}In (γ, n) ^{114}In monitor reaction, the most recent data from [11] obtained in measurements on a beam of quasi-monochromatic photons were used. The obtained values of the isomeric ratios of the yields η of the reaction ^{113}In (γ, n) $^{112m,\,g}$In are converted to the cross sections of the corresponding reactions by the photon difference method.

The experimental dependence of the ^{113}In(γ, n)^{112m}In reaction cross sections on the limiting energy of the bremsstrahlungs was approximated by the Lorentz function, whose parameters (the position of the maximum of the cross section E_m, the value of the cross section at the maximum σ_m, and the width of the distribution at half its height Γ) were determined by the method of least squares in the set of experimental values . The approximation parameters and the integral cross sections of the reaction are given in Table 3. The errors are estimated from the statistics of the registered reports.

Table 3: The reaction cross-section ^{113}In (γ, n) ^{112m}In

Reaction	E_m, MeV	Γ, MeV	σ_m, mb	σ_{int},(25 MeV)* MeV·mb	References
^{113}In(γ,n)^{112m}In	15,48±0,04	4,2±0,2	203±9	1315	This work
^{113}In(γ,n)^{112m}In**	15,77±0,05	4,1±0,2	205	1454	
^{113}In(γ,n)^{112m}In	15,67±0,05	4,7±0,3	214±10	1595	[12]
^{115}In(γ,n)^{114}In	15,29	4,0	265	1470	[10]

Note.

*σ_{int}– integral reaction cross section, upper limitintegration - 25 MeV.

**The calculation of the cross sections was carried out according to the program TALYS-1.0.

To evaluate and compare the experimental results, we calculated the reaction cross-section using the TALYS-1.0 software package [12]. As the energy distribution of gamma quanta-W (E_γ, E_m), in view of the fact that the thickness of the tungsten target converter was 2 mm, which is substantially smaller than the radiation length for tungsten, which is about 4.3 mm [13], the spectrum Schiff [13]. The results of theoretical calculations are also given in Table 2. As can be seen in Table 2, the value of the cross section at the maximum σm and the width of the distribution at half its height Γ agree with each other within the error of the measurement. The data given in Table. 2 over the cross section of the reactions make it possible to obtain an estimate of the isomeric ratio of the cross section $r = \sigma_m / \sigma_{tot}$ and the integrated reaction cross sections, which is Eγ = 15 MeV, respectively: r = 0.77 ± 0.02 and g = 0.89 ± 0.10. To evaluate and compare the experimental results, we calculated the reaction cross-section using the TALYS-1.0 software package [12]. As the energy distribution of gamma quanta-W (E_γ, E_m), in view of the fact that the thickness of the tungsten target converter was 2 mm, which is substantially smaller than the radiation length for tungsten, which is about 4.3 mm [13], the spectrum Schiff [13]. The results of theoretical calculations are also given in Table 2. As can be seen in Table 2, the value of the cross section at the maximum σm and the width of the distribution at half its height Γ agree with each other within the error of the measurement. The data given in Table. 2 over the cross section of the reactions make it possible to obtain an estimate of the isomeric ratio of the cross section $r = \sigma_m / \sigma_{tot}$ and the integrated reaction cross sections, which is E_γ = 15 MeV, respectively: r = 0.77 ± 0.02 and g = 0.89 ± 0.10.

The energy position of the maximum of the ^{113}In (γ, n) ^{112m}In reaction cross section within the margin of error coincides with the energy of the giant dipole resonance ^{113}In, determined by the empirical relation $E_m = 75 \cdot A^{-1/3}$, which is equal to 15.5 MeV.

In the case of the reaction (n, 2n) (Table 3), the data of all the works agree within the limits of measurement errors. The absolute error of the isomeric ratios of the reaction cross sections is determined by the statistical error of the counts in the photopic of the measured γ line, the efficiency of recording the γ radiation, and the error in the values of the cross sections of the monitors.

Table 3: Cross sections of the ground and isomeric state of the reaction ^{113}In (n,2n) $^{112m,\,g}$In

E_n, MeV	σ, mb		σ_m/σ_g	References
	m	g		
14,0	1176±70	280±20	4,2±0,4	This work
14,1	1240±136	297±33	4,2±0,6	[14]
14,3	1107±62	256±19	4,3±0,4	[15]
14,6	1188±69	303±17	3,9±0,3	[4]

Conclusion

We have measured the isomeric yield ratios for the ^{113}In(γ,n)^{112m,g}In reactions in the 12-35 MeV energy range. The energy dependence of the isomeric ratios of the ^{113}In(γ,n)^{112m,g}In reaction yields in the energy range 26-35 MeV was obtained for the first time. The obtained experimental results on the isomer ratios of the yields and cross sections for the (γ,n) and (n,2n) reactions on the ^{113}In nucleus can be used to elucidate the mechanism of photonuclear reactions in the energy region behind giant resonance, to create theoretical models for describing such reactions and to obtain information on the properties of highly excited nuclear states, and also on the expansion of the nuclear data base for isomeric ratios. Similar experimental data are currently not available for most nuclei. Also, the results obtained can be used in applied nuclear physics

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