Study of isomer ratio in (n,2n) and (γ,n) reactions on the ^{198}Hg nucleus

S.R. Palvanov[1], Kh.Z. Rustamova[1], J.R. Raimbaev[1,2,3], G.S. Palvanova[1], A. Tuymuradov[1]

[1]National University of Uzbekistan, Tashkent city, University street, 4, University street, Tashkent 100174
[2]Ulugh Beg Astronomical Institute, 33 Astronomicheskaya str., Tashkent, 100052, Uzbekistan
[3]Chirchiq State Pedagogical Institute, Chirchik city, 104 Amir Temur street
[4]Tashkent State Pedagogical University here, Uzbekistan, Tashkent, Bunyodkor avenue, 27

Palvanov1960@gmail.com, satimbay@yandex.ru

Abstract. The production cross sections and isomeric ratios of the cross-sections of (n,2n) reactions on ^{198,200}Hg nuclei at a neutron energy of 14.1 MeV have been measured by the induced activity method. The isomeric ratios of the photoneutron reaction yields (γ, n) were also measured at maximum bremsstrahlung energies of 15, 20, 25, 30, and 35 MeV. The experimental isomeric ratios are compared with the results of other works and the calculated results using the statistical model of the nucleus.

1. Introduction

The study of isomeric ratios is one of the most actual issues that gives the possibility of obtaining useful information about the reaction mechanism, in particular, on the moment of inertia of the nucleus, the spin dependence of the level density, and the character of transitions between highly excited nuclear states. Moreover, it can also help get data from the isomeric ratios of the yields of nuclear reactions which are necessary for replenishing nuclear data in this area and to optimize experiments in analytical and numerical studies using methods of activation analysis [1].

In the present work, the isomeric ratios of the cross-sections for the (n,2n) reaction on ^{198}Hg nuclei are studied using an induced activity method. The isomeric ratios of the reaction yields (γ, n) on the ^{198}Hg nucleus were also determined. In the bremsstrahlung energy range of 15–35 MeV, the values of isomeric ratios of reaction yields (Y_m/Y_g) were obtained for the first time.

2. Experimental technique

The studies were carried out on a high-current betatron SB-50 of the Research Institute of Applied Physics of the National University of Uzbekistan and a neutron generator NG-150 of the Institute of Nuclear Physics of the Academy of Sciences of the Republic of Uzbekistan [2]. The neutron generator NG-150 realizes fluxes of fast neutrons with energies ~ 2.4 and 14 MeV from the reactions D + d → ^{3}He + n or T + d→ α + n using deuterium and tritium targets. In this case, the neutron fluxes are ~10^8 and 10^{10} n/sec, respectively. The time of exposure to a neutron flux with the energy at 14 MeV is 50 min. The neutron flux is monitored using a natural isotopic aluminum plate, where it has been irradiated together with the targets. Samples of mercury oxide (HgO) weighing 2-3 g in the form of a disk 15 mm in diameter are used as targets. Experiments on the reaction (γ,n) have been carried out on the bremsstrahlung γ-beam of the SB-50 betatron at the maximum energies of bremsstrahlung $E_{\gamma max}$ =25, 30 and 35 MeV.

The induced γ-activity of the targets was measured on a Canberra γ -ray spectrometer, consisting of an HPGe germanium detector (with a relative efficiency of 15%, a resolution for the ^{60}Co 1332 keV line - 1.8 keV), a DSA 1000 digital analyzer, and a personal computer with the Genie software package. 2000 for acquisition and processing of gamma spectra. The energy scale of the detector was set by using commercial reference sources of ^{54}Mn, ^{57}Co, ^{60}Co, ^{109}Cd, ^{133}Ba, ^{137}Cs, ^{152}Eu, ^{210}Pb, and ^{241}Am. The measurements were performed in standard geometry, in which the detector was calibrated in terms of efficiency.

The population of the isomeric and basic levels was identified by γ-lines. The spectroscopic characteristics of the nuclei-products of the reaction (n, 2n), necessary for processing the results of measurements, are taken from [3, 4] and are given in Table 1, where Q is the reaction energy, I^{π} is the spin, and parity of the level, $T_{1/2}$ is the half-life of the nucleus, E_{γ}, is the energy of γ-quanta, I_{γ} is the intensity of γ-quanta of given energy for decay, p is the branching factor of the γ-transition.

Table 1. Spectroscopic characteristics of the nuclei understudy

Nuclear reaction	Q, MэB	I^{π}	$T_{1/2}$	E_{γ}, кэB	I_{γ}, %	*p*
^{198}Hg(n,2n)^{197m}Hg	- 8,56	$13/2^{+}$	23,8 h	133,9	30,2	0,93
^{198}Hg(n,2n)^{197,g}Hg	- 8,49	$1/2^{-}$	64,1h	191,5	0,55	

3. Results and discussion

To obtain the absolute values of the cross-sections of the ground and isomeric states, methods were used to compare the yields of the studied and monitor reactions. ^{27}Al (n, α)^{24}Na ($T_{1/2}$=15 h, E_{γ}=1368 keV) was used as a monitor reaction, the cross-section of which is: σ_m =114±6 mb at En =14.6±0.3 MeV [5].

The obtained experimental results on isomeric ratios of yields and cross-sections of reactions (n,2n) and (γ,n) on ^{198}Hg nuclei are given in Tables. 2 and 3.

Table 2. Cross sections for (n,2n) reactions on ^{198,200}Hg nuclei.

Nuclear reaction	E_n, MeV	σ, mb		σ_m/σ_g	Reference
		m	g		
^{198}Hg(n,2n)^{197}Hg	14,1	900±70	940±75	0,96±0,11	This work
	14.1	-	-	0,80±0,10	[6]
	14.4	885±80	1125±100	0,79±0,10	[7]
	14.7	910±85	1010±140	0,90±0.15	[8]
	14,02	930±60	1110±110	0,84±0,10	[9]

As can be seen from Table. 2, the data of all works are consistent within the measurement errors. The absolute error of the isomeric ratios of reaction cross sections is determined by the statistical error of counting in the photopeak of the measured γ-line, the efficiency of registration of γ-radiation, and the error in the values of the monitors' cross-sections.

The isomeric ratios of the yields d=Y_m/Y_g of the reaction (γ,n) on ^{198}Hg nuclei are given in Table. 3. Earlier in [10], the isomeric yield ratios Y_m/Y_g of the (γ,n) reaction on the ^{198}Hg nucleus were measured in the energy range of 10–17 MeV with a step of 0.5 MeV, the results of which, within the limits of errors, agree with our results. The results of [11] differ from the results of other works. The data of [11] were obtained on a scintillation spectrometer, the energy resolution of which is worse than that of modern semiconductor detectors. The relative probability of the formation of ^{197m,g}Hg isomeric states in the (n,2n) reaction is greater (~8 times) than in the photonuclear reaction (γ,n). This is probably due to the momentum introduced into the nucleus, which is greater in the case of the (n,2n)-reaction than in the case of the (γ,n)-reaction.

Table 3. Isomeric ratios of the yields of the reaction (γ,n) on the ^{198}Hg nucleus.

Reaction	$E_{\gamma max}$, MeV	Y_m/Y_g	Reference
$^{198}Hg(\gamma,n)^{197m,g}Hg$	15	0,087±0,060	This work
	20	0,111±0,006	This work
	25	0,114±0,006	This work
	30	0,113±0,006	This work
	30	0,113±0,006	This work
	35	0,112±0,006	This work
	17	0,112±0.055	[10]
	25	0,110±0,010	[11]
	30	0,05±0,01	[12]

In order to calculate the theoretical isomeric ratios of yields, we have used the TALYS-1.0 software package [12]. The program has several variants of model approaches to the description of the level density. Discrete level schemes are taken into account automatically. The complexity of calculations in this energy region is since the energy spectrum of bremsstrahlung γ-rays have a continuous behavior with a decrease from maximum $E_{\gamma max}$ values to zero. In the betatron, the bremsstrahlung target has been considered to be thin targets, and therefore the Schiff formula [14] was used to calculate the bremsstrahlung spectrum. The general scheme of the reaction is assumed to be the same as in Ref.[12], namely, first, the dipole γ-rays are absorbed on the nucleus with the formation of a compound nucleus, then the neutron is evaporated with the formation of the excited state of the final nucleus. The excitation of the daughter nucleus is removed by cascade emission of γ-rays, resulting in the formation of the ground or isomeric state of the final nucleus.

The density of nuclear levels was calculated using the Beta-Bloch formula [14], the spin part of which has the form

$$\rho(J) = (2J+1)\, exp\left[-(J+\frac{1}{2})^2/2\sigma^2\right]$$

It was possible to improve the quantitative agreement between calculations and experiments by fixing the spin confinement parameter σ. In this case, the satisfactory agreement is reached at $\sigma = 3\hbar$.

4. Conclusion

It is observed from an analysis of the data given in Tables 3 that experimental studies of the excitation of isomeric states in photonuclear reactions of the (γ,n) type have been carried out mainly in the range of energies 10-17 MeV which corresponds to the range of giant dipole resonance. In the range of energies, the above-mentioned giant resonance dependence of isomeric ratios from its energy has been poorly understood. The studies allow the possibility of obtaining information about the nuclear density levels and contributions of direct processes to the photonuclear reaction mechanism in the energy range.

The experimental results obtained in this work can be used to assess the analytical capabilities of activation analysis, for planning a new type of such experiments in studies of isomeric ratios in nuclear reactions, and to explain physical mechanisms reactions.

5. Acknowledgments

The authors are grateful to the staff of the Institute of Nuclear Physics M. Kayumov, O. Zhuraev, and F. Ergashev for irradiating the samples with the neutron generator NG-150. Zh. Rakhmonov for assistance in the measurements. S.V. Artyomov for a useful discussion of experimental results. The research was conducted with the support provided by the grant OT-F2-12 of the Ministry of Innovation Development of the Republic of Uzbekistan.

References

[1] Palvanov, S.R., Egamova, F.R., Ramazanov, A.K., Palvanova, G.S., Inoyatov, A.K. Physics of Particles and Nuclei Lettersthis link is disabled, 2021, 18(6), pp. 672–675

[2] http://www.inp.uz.

[3] Lederer C., Shirley V. Table of Isotopes. New York: Wiley & Sons. Inc. 2001.

[4] Randa Z., Kreisinger F. // Journal of Radioanalytical Chemistry. 1983. v.77. N2. P. 279.

[5] Holub E., Cindro N. // Jour. of Physics, Part G (Nucl.and Part.Phys.). 1976. V.2. P.405.

[6] Temperley J.K. // Phys. Rev.1969. V.C178, P.254-258.

[7] Hankla A.K., Fink R.W., Hamilton J.H. //Nuclear Physics, Section A,1972, V.180, P.157-162.

[8] Qaim S.M. //Phys. Rev. 1970. V.C178. P. 343-347.

[9] Kasugai Y., Maekawa F..,.Ikeda Y., Takeuchi H. //J. of Nuclear Science and Technology. 2011. V. 38. No.12. P. 1048-1051.

[10] Zheltonozhsky V.A., Mazur V.M., Bigan Z.M. // Physics of atomic nuclei, 2004.- V.67, № 6.- pp. 899 - 902.

[11] Gangrskiy Yu.P., Zuzaan P., Kolesnikpv N.N., Lukashik V.G., Tonchev A.P. Izv. Rossiiskoi Akademii Nauk, Ser.Fiz, 2001, Vol. 65, № 1, pp. 111-116

[12] Davydov M. G.. Magera V. G.. and Trukhov A. V. Isomer yield (cross section) ratios of photonuclear reactions // Atomic Energy. 1987. V.62. No. 4. P. 232–243.

[13] Koning A.J., Hilaire S., Duijvestijn M.C. TALYS: Comprehensive nuclear reaction modeling // Proc. of the Int. Conf. on Nuclear Data for Science and Technology. 2005. - Vol. 769. - P. 1154 - 1159.

[14] Mazur V.M. Nuclear isomeric states excitation in the (γ. n) reaction within the dipole giant resonance region. //. Fiz. Elem. Chastits At. Yadra. 2000. vol. 31. no. 2. p. 1043 [Phys. Part. Nucl. (Engl. Transl.). 2000. vol. 31. no. 2. p. 188].