EXCITATION MECHANISM OF ISOMER STATES OF ^{197}Pt AND ^{197}Hg NUCLEI IN PHOTONEUTRON REACTIONS IN THE ENERGY REGION OF A GIANT *E*1-RESONANCE

V. M. MAZUR, V. A. ZHELTONOZHSKY[1], Z. M. BIGAN

Institute of Electron Physics, Nat. Acad. Sci. of Ukraine, *(21, Universitetska Str., Uzhgorod 88016, Ukraine)*, [1]Institute for Nuclear Research, Nat. Acad. Sci. of Ukraine, *(47, Nauky Prosp., Kyiv 03028, Ukraine)*

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Within the 8 – 17 MeV energy range, the dependence of isomer yield ratios on the gamma-quanta energy in the ^{198}Pt (γ, n) ^{197m,g}Pt and ^{198}Hg (γ, n) ^{197m,g}Hg reactions is studied. The experimental results are compared with those calculated within the framework of the cascade-evaporation model as well as obtained under the influence of particles. The mechanisms of isomer states population are discussed.

It is known that the gross-characteristics of a giant *E*1-resonance (GR) are fairly well studied for a wide circle of nuclei [1, 2], while the processes of its decay are far from the same level and require additional efforts of both experimentalists and theorists.

The region of transient nuclei with masses $A \sim 185 \div 200$, which the platinum and mercury isotopes belong to, lies between strongly deformed nuclei of rare-earth elements and the region of spherical nuclei close to lead. Analyzing an array of data on low-energy excitation spectra [3 – 5], one may note a complicated character of variation of the shape of the nuclei under study. The low-energy excitation spectrum of the above nuclei is formed to a considerable extent by the one-particle (hole) states $3p_{1/2}$, $2f_{5/2}$, $3p_{3/2}$, $1i_{13/2}$. The latter state determines the presence of the isomer level with $J^{\pi} = 13/2^{+}$. The studies on the mechanisms of the metastable state population and the dependence of the isomer ratio variation on the excitation energy for these isotopes could provide an additional information on the origin of nuclei from that region.

No investigations of the isomer ratio dependence on the gamma-quanta energy of the $(\gamma, n)^m$ reactions for platinum-197 and mercury-197 nuclei have been carried out. Up to date, only a few works performed with the natural isotope composition targets are available dealing with the measurements of the isomer yield ratios, i.e. the ratios of excited isomer level yield Y_m to that for the ground level Y_g: $d = Y_m / Y_g$ in the $(\gamma, n)^m$ reaction at a single energy point and the maximal bremsstrahlung gamma-spectrum energy $E_{\gamma\,max} = 30$ MeV [6, 7].

The ^{198}Pt (γ, n) ^{197m,g}Pt and ^{198}Hg (γ, n) ^{197m,g}Hg reactions were studied by us on the bremsstrahlung gamma-quanta beam produced by an M-30 microtron at the Institute of Electron Physics. The yields were measured within the 8 – 17 MeV energy range. Here one should keep in mind that the threshold of the (γ, n) reaction is 7.8 MeV for the ^{198}Pt isotope and 8.3 MeV – for ^{198}Hg. As targets, we used the natural mercury oxide (HgO) and metallic platinum plates. The induced activity of irradiated samples was measured using a Ge(Li)-detector (100 cm^3 in volume). Fig. 1 shows the apparatus gamma-spectrum obtained at the Pt sample irradiation by the bremsstrahlung spectrum with the maximal energy $E_{\gamma\,max} = 16$ MeV. In this case, the irradiation time was 12 min and the measuring time – 20 min. The spectrum reveals distinct lines responsible for the isomer and ground state decay. The measuring procedure is described in more detail in [8, 9].

Platinum-197 and mercury-197 nuclei produced in the (γ, n) reactions are unstable. In both cases, the stable gold-197 isotope is populated due to the decay. Since the ground states of the isotopes under study are unstable, the direct experimental result may give the isomer yield ratio using the following formula [10]:

$$d = \frac{Y_m}{Y_g} = \frac{\lambda_g - \lambda_m}{\left\{\left[c \frac{N_g}{N_m} \frac{\varphi_m}{\varphi_g} (\lambda_g - \lambda_m) - p \lambda_g \right] \frac{\lambda_g}{\lambda_m} \frac{f_m(t)}{f_g(t)}\right\} + p\lambda_m}, \quad (1)$$

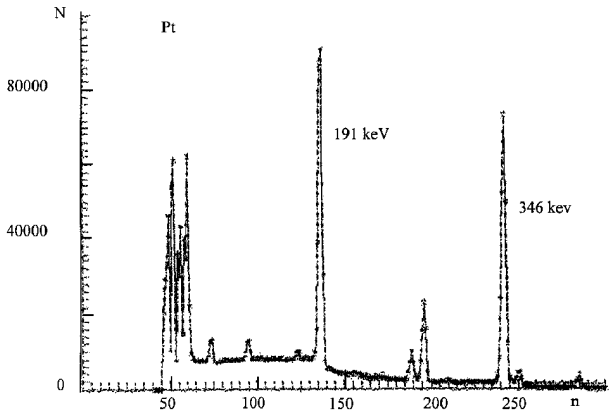

Fig. 1. Gamma-spectrum area of the natural platinum after irradiating by bremsstrahlung gamma-radiation with the 16 MeV maximal energy

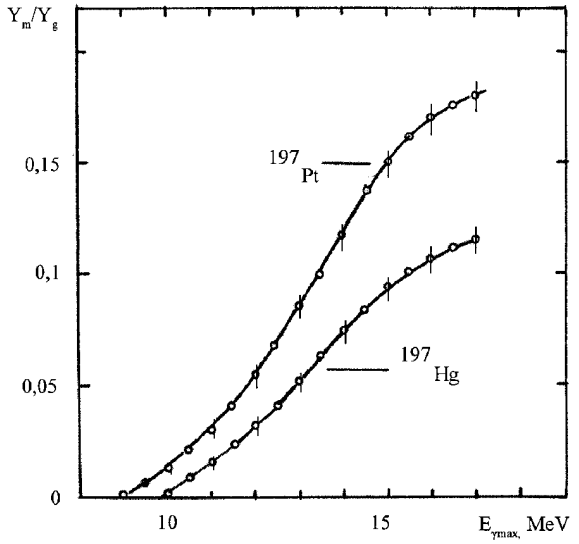

Fig. 2. Experimental isomer ratios for the ^{197}Pt, ^{197}Hg isotopes as functions of $E_{\gamma\,\max}$

where $f_{m,g} = (1 - e^{-\lambda_{m,g} t_1})\, e^{-\lambda_{m,g} t_2}\, (1 - e^{-\lambda_{m,g} t_3})$, $\varphi_{m,g} = \xi_{m,g}\, k_{m,g}\, \alpha_{m,g}$. Here ξ_m, ξ_g are detector photoefficiencies at the decay γ-line detection for the isomer (m) and ground (g) states, respectively; k_m, k_g are self-absorption corrections for the corresponding lines; α_m, α_g are the intensities of lines responsible for the isomer (m) and ground (g) state decays; λ_m, λ_g are the decay constants for the metastable and ground states; t_1, t_2, t_3 are the irradiation, waiting, and measuring times, respectively; N_m, N_g are the numbers of pulses in the corresponding photopeaks; c is the pulse overlapping and miscount corrections; p is the branching ratio.

Spectroscopic characteristics – spin-parity of the ground and isomer states, J^{π}; the spin difference for the ground J_g and isomer J_m states, $\Delta J = |J_g - J_m|$; gamma-line energies based on which the E_γ decay was measured; the line intensity I, half-decay period $T_{1/2}$, and branching ratio p – are taken from [4, 5] and are shown in the table. The accurate half-decay period value for the platinum-187 ground state ($T_{1/2} = (19.96 \pm 0.05)$ h) has taken from [11].

Experimental isomer ratios $d = Y_m / Y_g$ obtained in the ^{198}Pt (γ, n) ^{197m,g}Pt and ^{198}Hg (γ, n) ^{197m,g}Hg reactions are shown in Fig. 2. The relative statistical error at the energy $E_{\gamma\,\max} = 16$ MeV was 0.2%. The determined threshold of the ^{198}Pt (γ, n) ^{197m,g}Pt reaction is (8.9 ± 0.15) MeV, what is by 0.9 MeV higher than that of the $(\gamma, n)^m$ reaction for the same nuclei (i.e., the $(\gamma, n)^m$ reaction threshold plus the isomer level energy E_m). The Hg (γ, n) ^{197m} reaction threshold is, respectively, (9.7 ± 0.15) MeV which exceeds the calculated threshold energy for the $(\gamma, n)^m$ reaction by 1.1 MeV. The presence of such a large threshold of metastable state population is due to a relatively large spin difference ΔJ for the ground state of the parent nucleus and the isomer product nucleus state. To populate the metastable state by the γ-quanta cascade, one needs at least five transitions or the availability of fast (~ 1 MeV energy) neutrons that could provide a change in the angular momentum of a daughter nucleus.

Above the $(\gamma, n)^m$ reaction threshold, the isomer yield ratio increases sharply and, in the region of 16 – 17 MeV, has a tendency of going to a plateau reaching a remarkable value $d = 0.171$ for ^{197}Pt and $d = 0.104$ for ^{197}Hg at $E_{\gamma\,\max} = 16$ MeV.

We have calculated the isomer ratios within the framework of the statistical cascade-evaporation model [12, 15] according to the following scheme: the nucleus absorbs a gamma-quantum with energy E. The nucleus formed with the (J_c, π_c) spin-parity ejects a neutron with angular momentum l and energy ε, while the

Spectroscopic characteristics of the ground and isomer states for the ^{197}Pt and ^{197}Hg isotopes

Isotope	J_m^{π}, J_g^{π}	$\Delta J = \lvert J_g - J_m \rvert$	Line energy E_γ (keV)	Line intensity I(%)	$T_{1/2}$ (h)	p
^{197m}Pt	$13/2^+$	6	346	12,4	1,573	0,97
^{197g}Pt	$1/2^-$		191,4	6,7	19,9	
^{197m}Hg	$11/2^+$	6	133,9	34,2	23,8	0,935
^{197g}Hg	$1/2^-$		191	0,96	64,4	

nucleus transits to the (J_f, π_f) state. The reduced probability of this process is

$$P(J_c, \pi_c, J_f, \pi_f) = B\rho(J_f) \sum_{S=|J_f - s|}^{J_f + s} \sum_{l=|J_c - S|}^{J_c + S} T_l(\varepsilon)\, \omega_l(\pi_c, \pi_f), \tag{2}$$

where B is a constant, s is the spin of an emitted neutron, $T_l(\varepsilon)$ is the barrier penetration coefficient [14, 15], $\omega_l(\pi_c, \pi_f) = [1 + (-1)^l \pi_f \pi_c]/2$ is a coefficient that is related to the state parity. The average neutron energy ε_n was taken as the neutron energy ε. For the level density, we took the ratio from the Fermi-gas model [16 – 18]:

$$\rho(U, J) = \rho(U)\,\rho(J) = \frac{1}{24\sqrt{2}} \frac{2J+1}{\sigma^3 a^{1/4} U^{5/4}} \times$$

$$\times \exp\left\{\sqrt{aU} - \frac{(J+1/2)^2}{2\sigma^2}\right\}, \tag{3}$$

where $\rho(U)$ and $\rho(J)$ are the energy and spin parts of the level density formula, respectively; a is the level density energy parameter; σ is the spin cut-off parameter that, according to [17], could be calculated by the following formula: $\sigma^2 = 0.889\sqrt{aU}\, A^{2/3}$. Here, A is the mass number, U is the effective excitation energy determined as $U = E - \Delta$ [17], where Δ is the coupling energy. E, J are the energy and spin of excited levels, respectively.

The excitation of a produced daughter nucleus with (J_f, π_f) spin-parity is drawn off by a cascade of dipole gamma-transitions, the latter of which just populates the isomer or ground state. In this case, the average transition energy is

$$E = 4\sqrt{U/a - \sigma/a^2}. \tag{4}$$

A satisfactory agreement between experiment and calculations at the 14 – 16 MeV energy of absorbed gamma-quanta is achieved by fixing the spin limiting parameter $\sigma = 3.4$ for ^{198}Pt and $\sigma = 3.0$ for ^{198}Hg.

For mercury-197 nuclei, the measurements of isomer cross section ratios $R = \sigma_m / (\sigma_m + \sigma_g)$ were carried out for reactions under the influence of (p, n), (d, 2n), (d, p), (n, 2n), and other particles [19]. The comparison of such data with those obtained in this work for the (γ, n) reactions is shown in Fig. 3. The isomer yield ratio was taken in the following form: $\eta = Y_m/(Y_m + Y_g) = d/(d+1)$.

As seen from Fig. 3 the isomer ratios appear to increase in all the cases with incident particle energy. At the same energies, the isomer ratio obtained in

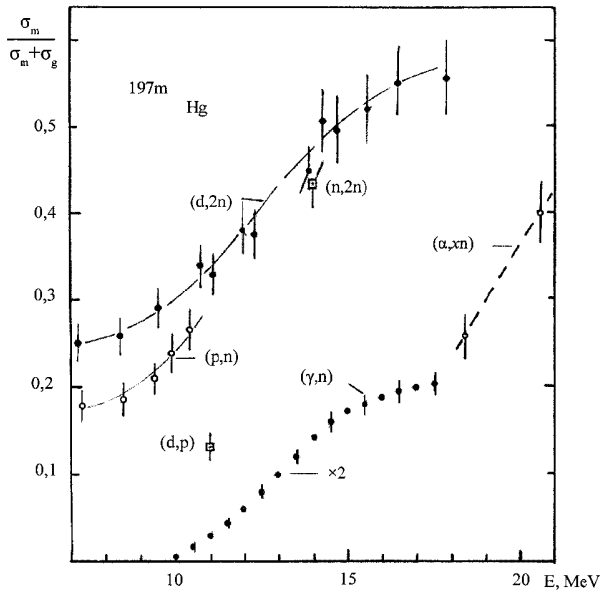

Fig. 3. Isomer ratios for a ^{197}Hg nucleus obtained in the (γ, n) reaction in the present work as compared to those obtained in the reaction under the influence of particles

the (γ, n) reactions is considerably less than that for particles. Such a situation is obvious since the particles bring large angular momenta to a nucleus, and the above momenta are also increased with increasing energy, whereas, in the (γ, n) reactions, the gamma-quantum brings the almost fixed moment $l = 1$.

A certain exception is the reaction of radiative trapping of thermal neutrons, the isomer ratio R for which is 0.042 ± 0.008 and is close to the values for the (γ, n) reaction. In this case, a neutron brings the $l = 0$ momentum (the spin of a neutron is $s = 1/2$), and the isomer ratio is almost fully determined by the gamma-quanta cascade characteristics. Thus, the isomer state population in the (n, γ) reaction is similar to the same process on inelastic gamma-quanta scattering close to the (γ, n) reaction threshold. The available results on the excitation of the isomer with $J^\pi = 13/2$ for the close ^{199}Hg isotope in the (γ, γ') reaction [20] give the isomer cross section ratio $R \sim 0.01$ for 6.5 – 7.0 MeV. This, taking into account some difference in the excitation energies, gives a value close to the isomer ratio for the (n, γ) reaction.

Some closer values to the photoneutron ones are obtained for the isomer ratio for the ^{196}Hg (d, p) ^{197m}Hg reaction. Such a proximity is explained by the fact that the (d, p) reaction passes through the catch-up mechanism. In this case, far not the whole angular momentum of a deuton is transferred to the target nucleus, and the energy of the daughter nucleus remains insignificant, at least less than the

threshold energy of neutron emission. Due to the gamma-quanta cascade, as shown above, the isomer ratio may change only slightly.

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