EXCITATION CROSS SECTIONS FOR THE $13/2^+$ ISOMER STATE OF MERCURY-199 NUCLEUS IN THE (γ, γ') AND (γ, n) REACTIONS

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Isomer state excitation cross sections for the ^{199}Hg(γ,γ')^{199m}Hg and ^{200}Hg(γ,n)^{199m}Hg reactions have been studied within the gamma-quantum energy region 4—17 MeV. The experimental isomer ratios are compared with those calculated within the framework of the cascade-evaporation model.

The studies of the partial photo-nuclear reactions with the daughter nucleus excited states being fixed have become recently one of the basic sources of new information on the giant E1-resonance (GR). The above reactions are a quite convenient test for checking the conformity of theoretical approaches for the description of decay mechanisms for highly excited collective states, which the GR states belong to. The studies of the excitation of isomer states in the inelastic scattering of gamma-quanta on nuclei, in the photo-neutron reactions, etc. are just in the course of the above tasks.

This paper is devoted to the experimental investigation of the excitation of the ^{199m}Hg ($T_{1/2}$=42.6 min) isomer state in the ^{199}Hg(γ,γ')^{199m}Hg and ^{200}Hg(γ,n)^{199m}Hg reactions.

The present work was carried out with a bremsstrahlung gamma-quanta beam produced by an M-30 microtron (Institute of Electron Physics, Ukrainian NAS). The accelerated electron beam was transported from the accelerator and directed to a 1-mm-thick tantalum target. The bremsstrahlung gamma-quanta beam was formed by a collimator and then, having passed a thin-wall ionization chamber, fell onto the sample under study. The secondary-emission monitor was used to control the accelerated electron beam. The measurement procedure was as follows. At the moment of mounting the target under study on the beam path, the gamma radiation intensity passing the target was detected. When the specified irradiation time elapsed, the target was transported to the measuring unit. The targets under study were prepared in the form of 20-mm disks made of a pressed powder of natural mercury oxide (HgO) (a weight of 2 g). The induced activity was measured by a gamma-spectrometer based on a semiconductor detector DTDK-100. The apparatus miscounts and the absorption of gamma-quanta in the target were taken into account. The spectroscopic characteristics of the levels under study were quoted from [1]. The isomer ^{199m}Hg level population was identified with respect to the lines with E=374 and 158 keV. Hg-199, 200 nuclei should be to a great extent considered to be transient, though they are distinctly distanced from the closed shell with N=126. The metastable ^{199m}Hg state is a hole of the $1i13/2$ state with the $13/2^+$ spin-parity. The experimental procedure is described in more details elsewhere [2, 3].

Since the spin difference ΔJ between the ground J_g and isomer J_m states of the Hg-199 nuclei (J_g—J_m) is 6, that is a considerable value, the population of the $J^\pi = 13/2^+$-level upon the inelastic scattering of gamma-quanta occurs in the form of a cascade of gamma-transitions (most probably – dipole transitions) via the activation levels. Using the radioactive sources, the availability of an activation level at an energy below 1.33 MeV was proved. For the (1.38 ± 0.01) MeV level, the photoactivation cross section is $\sigma_m = (2.2^{+3.8}_{-0.7})\cdot 10^{-27}$ cm$^2\cdot$eV [4]. The photoexcitation cross section for the isomer state increases sharply with the energy of gamma-

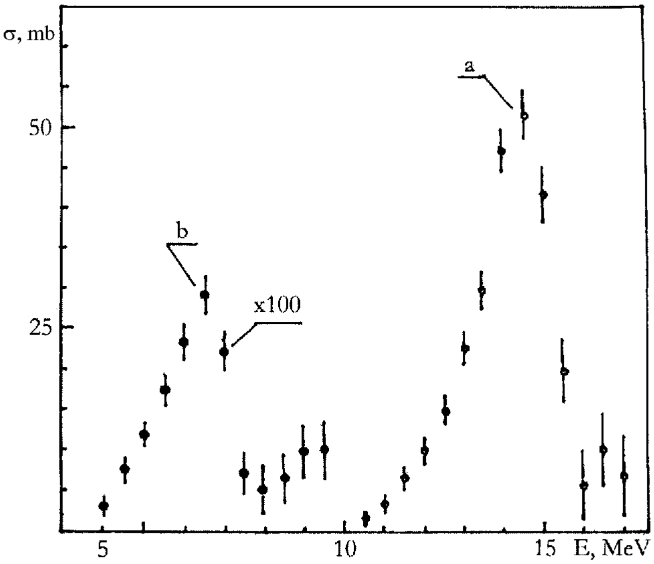

Fig. 1. Excitation cross-sections for the isomer states for Hg-199 in the (γ, n) (*a*) and (γ, γ') (*b*) reactions

quanta. In the region of the photo-neutron reaction threshold, the nuclear photoabsorption is determined by the "wings" of a giant dipole resonance that has a Lorentz-line shape.

The yield curves for the ^{199}Hg(γ,γ')^{199m}Hg and ^{200}Hg(γ,n)^{199m}Hg reactions measured with the $\Delta E = 0.5$ MeV step were the direct results of the experiment. The measurements were carried out in the region of the maximal bremsstrahlung gamma-spectrum energies ($E_m = 4 \div 17$ MeV). In the 4–10 MeV energy range, the excitation of the metastable ^{199m}Hg – state occurs due to the inelastic reaction ^{199}Hg(γ,γ')^{199m}Hg. At the energies E_m above 10 MeV the ^{200}Hg(γ, n)^{199m}Hg reaction channel opens. The (γ, n)^m reaction yield is two orders larger that that for the (γ, γ')^m reaction. Since we have used mercury targets with the natural isotope composition, the probable contribution from the (γ, γ') reaction was also taken into account. This is of special importance in the near-threshold region of the (γ, n)^m reaction. In this case, the ^{199}Hg(γ, γ')^{199m}Hg reaction yield behaves itself above 9 MeV like that of the (γ, γ')^m reaction for the neighboring heavy nuclei, for which the results obtained with isotopically enriched targets [5] are available. The task is facilitated by the fact that the (γ, γ')^m reaction yields in the region under consideration reach a plateau and then vary slightly. The (γ, γ')^m reaction threshold measured by us is (10.2 ± 0.2) MeV.

The cross sections were calculated from the yield curves in accordance with the Penfold-Leiss method [6]. The results obtained are shown in Fig. 1. Solid circles denote the ^{199}Hg(γ, γ')^{199m}Hg reaction cross section. This is a single-hump curve with a maximum of 0.29±0.025 mb at 6.5 MeV. The position of the maximum almost coincides with the threshold of the (γ, n) reaction in the ^{199}Hg nucleus, being equal to 6.6 MeV. The decrease of the (γ, γ')^m reaction cross section above the (γ, n) reaction threshold is explained by the competition of the gamma-quanta scattering reaction channel with those accompanied by the particle (neutron) emission, which results in a general decrease of scattering cross sections above the (γ, n) reaction threshold.

Open circles in Fig. 1 denote the ^{200}Hg(γ, n)^{199m}Hg reaction cross section. It is seen that the cross section of this reaction exceeds that of the (γ, γ')^m reaction by two orders due to a general increase of the photoabsorption cross section in the region of a giant dipole resonance. The maximum of the cross section $\sigma(\gamma, \mathrm{n})^m$ is (52.7 ± 5.5) mb at 14.5 MeV. A comparison of this value with the total (γ, n) reaction cross section for natural mercury [7] shows that its maximum is slightly shifted towards higher energies. We have approximated the experimental cross section for the ^{200}Hg(γ, n)^{199m}Hg reaction by a Lorentz curve. This procedure was performed by the least-square method in the 12—16 MeV energy interval with the following parameters of the Lorentz curve: $\sigma_0 = 51.9 \pm 0.6$ mb, $E_0 = (14.5.9 \pm 0.07)$ MeV, $\Gamma_0 = 2.76 \pm 0.04$ MeV. Here, σ_0 is the maximum cross section value, E_0 is the energy of the maximum and Γ_0 is the resonance half-width. The (γ, γ')^m reaction cross section agrees within the limits of error with the results of [8], while that for the ^{200}Hg(γ, n)^{199m}Hg reaction was obtained for the first time.

The ground state of the ^{200}Hg(γ, n)^{199m}Hg reaction products is stable, but the availability of the total cross section for the (γ, n) reaction [6] allows the experimental isomer ratios of cross sections $r = \sigma_m/\sigma_t = \sigma_m/(\sigma_m + \sigma_g)$ both for the (γ,n) reaction and for the (γ, γ')^m reaction to be obtained. Here, σ_t is the total cross section of the (γ, n) reaction, and σ_m and σ_g are the population cross sections for the isomer (m) and ground (g) states, respectively. To evaluate the total photoabsorption cross section in the 6—7 MeV region, we have used the results of extrapolation of the Lorentzian values that approximate the total cross section of the (γ, n) reaction in the low-energy region. The isomer ratios for the (γ, γ')^m and (γ, n)^m reactions were evaluated in the region of their maximal cross sections, i.e. where the relative error of the determination of r

is minimal. The results obtained are shown in Fig. 2 (circles). Figure 2,*a* presents the isomer ratios for the ^{199}Hg(γ, γ')^{199m}Hg reaction, while Fig. 2,*b* does those for the ^{200}Hg(γ, n)^{199m}Hg reaction.

The solid lines in Fig. 2 correspond to the isomer ratio calculations carried out in terms of the drop-evaporation model [9, 10]. It was assumed in the above calculations that the dipole gamma-quantum is absorbed, and the excitation of the daughter nucleus is removed by a cascade of dipole gamma-transitions, the last of which populates the ground or isomer state.

The probability of the formation of a compound nucleus with spin-parity (J_c, π_c) is considered to be proportional to the level density with relevant characteristics. The nuclear level density was calculated according to the Bethe—Bloch formula [11, 12], the spin part of which has a following form:

$$\rho(J) = (2J+1)\exp[-(J+(1/2)^2/2\sigma^2], \qquad (1)$$

where σ^2 is the spin limiting parameter which is determined [12] by the relation

$$\sigma^2 = 0.0889\sqrt{aU}A^{2/3}. \qquad (2)$$

Here, A is the mass number, a is the level density parameter, and U is the effective excitation energy [13].

In the case of the (γ, n) reaction, the reduced probability P of the emission of a neutron with momentum l and energy ε_n by the compound nucleus as well as its transition to the state (J_f, π_f) of the daughter was calculated by the formula [9]

$$P(J_c,\ \pi_c;\ J_f,\ \pi_f) =$$

$$= B\rho(I_f)\sum_{S=|J_f-S|}^{J_f+S}\ \sum_{S=|J_c-S|}^{J_c+S} T_l(\varepsilon)\omega_l(\pi_c,\ \pi_f), \qquad (3)$$

where B is a constant, S is the emitted neutron spin, $T_l(\varepsilon)$ is the barrier permeability coefficient [14], $\omega_l(\pi_c,\ \pi_f) = [1-(-1)^l\pi_c\pi_f]/2$ is the coefficient involving the state parity, and ε is the neutron energy taken equal to its average energy $\overline{\varepsilon}_n$.

The calculation procedure is described in detail in [10]. Solid curve, *1* in Figs. 2,*a*, 2,*b* denotes the calculated data with non-free parameters, curve, *2* is the result of calculations with the fixed spin limiting parameter $\sigma = 2.5$ and curve *3* is that at $\sigma = 3.0$. The calculations indicate correctly the tendency of the isomer ratio r to increase with the energy of gamma-quanta. In the gamma-quantum energy region of 14—15 MeV for the (γ,n)^m reaction and $E \approx 6$ MeV for the (γ,γ')^m reaction, the calculations agree fairly well with experimental data with the spin limiting parameter σ being fixed at the 2.5—3.0 level.

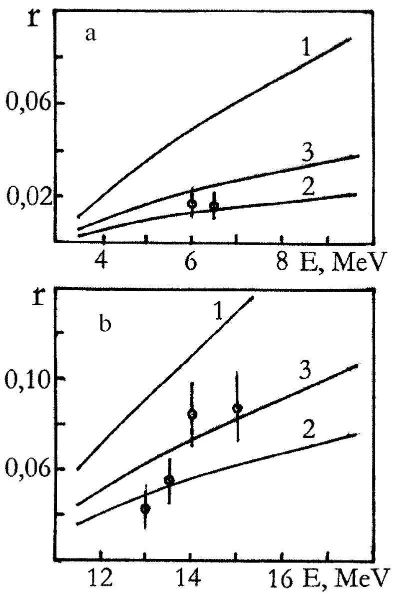

Fig. 2. Experimental isomeric cross-section ratio for the reactions (γ, γ')^m (*a*) and (γ, n)^m(*b*) in comparison with the predictions of calculations

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ПЕРЕРІЗИ ЗБУДЖЕННЯ ІЗОМЕРНОГО СТАНУ $13/2^+$ ЯДРА РТУТІ-199 В РЕАКЦІЯХ (γ,γ') І $(\gamma,$ n)

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Резюме

В області енергій гамма-квантів 4—17 МеВ досліджено перерізи збудження ізомерних станів в реакціях ^{199}Hg$(\gamma,\gamma')^{199m}$Hg і ^{200}Hg $(\gamma$n$)^{199m}$Hg. Одержані експериментальні ізомерні відношення порівнюються з розрахунками в рамках каскадно-випарювальної моделі.