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BARIUM ISOTOPES AS THE OBJECTS FOR STUDYING THE ISOMER RATIOS

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The cross-sections of excitation of isomeric states in (γ,n) reactions on barium-(129, 131, 135) isotopes in the energy range 8-17 MeV are investigated on the bremsstrahlung of the microtron M-30.

Recently the main emphasis in the investigation of the giant dipole resonance (GDR) properties have been changed from studying its gross characteristics to that of its decay mechanisms. This direction includes also the studies of excitation processes and cross-section for low-lying isomeric states (IS) of atomic nuclei.

The goal of the present investigation was to measure the IS excitation cross-section and study the isomeric ratios (IR) for the ^{130}Ba, ^{132}Ba, ^{136}Ba isotopes in the (γ,n) reactions within the 8 – 18 MeV energy range. The barium isotopes have been chosen as the objects of studies for several reasons. The low-lying barium isotope excited states are formed by the $1h_{11/2}$, $2d_{3/2}$, $3S_{1/2}$ states, of which the $1h_{11/2}$ state are the isomer ones with a significant spin. IS are excited in the (γ,n) reactions on all the even-even Ba isotopes allowing to trace the evolution of IR characteristics within a considerable mass interval of $130 < A < 138$, where the ^{138}Ba isotope belongs to magic ones with N=82.

The measurement were carried out at the bremsstrahlung beam of the IEP M-30 microtron. The induced activity of irradiated Ba samples was measured using the Ge(Li) detector (100 cm^3 volume). The experimental conditions are described in more detail elsewhere [1, 2].

The principal decay characteristics of the Ba isotopes in both ground and isomeric states where taken from [3, 4]. The half-decay periods and energies of gamma-transitions for these states differ considerably and this has allowed the simultaneous measurements of IS decays to be carried out almost for all isotopes under study by using natural isotope-composition samples.

The direct result of the measurements is the $Y_i(E_{\gamma m})$ yields for IS excitation at different maximal bremsstalhlung energies E_m. The measurement was carried out by a relative method by comparing the areas of photopeaks produced by the ^{129m}Ba, ^{131m}Ba, ^{135m}Ba IS decay and the 661 keV ^{137}Ba line area, the $Y_i(E_{\gamma m})$ yield of which in the ^{138}Ba(γ,n)^{137}Ba reaction was measured earlier [5], and the $(\gamma,n)^m$ reaction cross-section for ^{138}Ba is well defined. The yield is related to the effective cross-section for the reaction under study by the following integral equation:

$$Y\left(E_{\gamma m}\right)=\int_{E_{th}}^{E_{\gamma m}}\sigma(E)\Phi\left(E,E_{\gamma m}\right)dE \qquad (1)$$

Here E_{th} is the $(\gamma,n)^m$ reaction threshold , $E_{\gamma m}$ being the maximum bremsstrahlung spectrum energy, $\sigma(E)$ being the reaction cross-section, $\Phi(E, E_{\gamma m})$ being the bremsstrahlung spectrum.

The possible contribution of interfering reactions (n,n'), (n,γ) was determined in the separate experiment. It has been found that in the energy range under study one may neglect such contribution. Since the used samples contained ^{135}Ba and ^{137}Ba isotopes, the contribution of the $(\gamma,\gamma')^m$ reaction to the ^{136}Ba(γ,n)^{135m}Ba and ^{138}Ba(γ,n)^{137m}Ba yields has also been taken into account. And though in the 15–16 MeV region this contribution was negligible, close to the (γ,n) reaction threshold it was rather significant and was taken into account by calculating the $(\gamma,\gamma')^m$ reaction yields from the known cross-sections and comparing them with the $(\gamma,n)^m$ reaction yields.

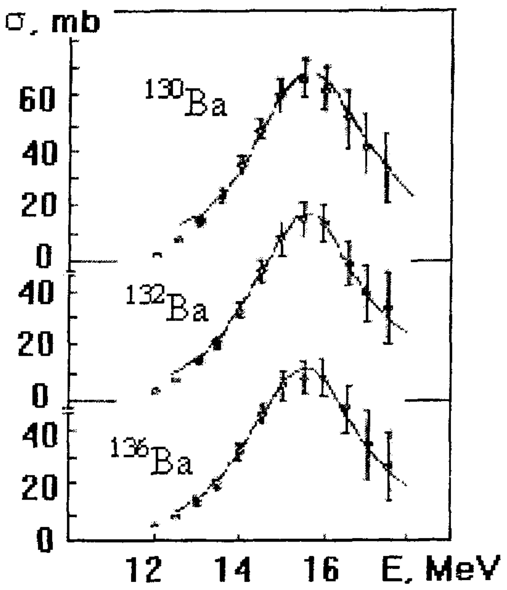

Fig. 1. The isomeric state excitation cross-section for the (γ, n) reaction on the barium isotopes.

The reverse Penfold-Liss matrix method [6] was used for calculating $\sigma_m(E)$ cross-section. The latter were calculated with the ΔE=1 MeV step. Figure 1 illustrates the IS excitation cross-section $\sigma_m(E)$ for the $^{130}Ba(\gamma,n)^{129m}Ba$, $^{132}Ba(\gamma,n)^{131m}Ba$ and $^{136}Ba(\gamma,n)^{135m}Ba$ reactions. Solid curves in Fig.1 denote the results of approximating these cross-sections by the Lorentz curves.

$$\sigma(E) = \sigma_1 \frac{E^2\Gamma_1^2}{(E^2 - E_1^2)^2 - E^2\Gamma_1^2}$$

The approximation parameters of the cross-sections were as follows: σ_1 is the cross-section in the maximum, E_1 is the energy of the maximum, Γ_1 is the half-width (see Table 1).

Table 1. Lorentz curves parameters used for approximating the isomeric state excitation cross-sections on the barium isotopes.

Isotope	σ_1, mb	E_1, MeV	Γ_1, MeV	$(\pi/2)\sigma_1\Gamma_1=\sigma_{int}$, mb·MeV
^{129m}Ba	68,6	15,6	3,26	351
^{131m}Ba	68,3	15,6	3,06	328
^{135m}Ba	62,1	15,5	3,19	311
^{137m}Ba	51,4	15,5	3,3	266

Table 2. Lorentzian parameters used to approximate the E1 Giant resonance in barium isotopes.

Isotope	Γ_0, MeV	E_0, MeV	σ_0, mb	$(\pi/2)\sigma_0\Gamma_0=\sigma_{int}$, mb·MeV
^{130}Ba	6,55	15,62	254	2615
^{132}Ba	6,21	15,53	272	2648
^{136}Ba	5,46	15,38	314	2693
^{138}Ba	4,09	15,29	356	2733

Table 2 presents the Lorentzian parameters σ_0, Γ_0, E_0, that approximate tatal cross-section σ_n for (γ, n) reactions in ^{130}Ba, ^{132}Ba, ^{136}Ba and ^{138}Ba. The parameters were estimated by the relations [7,8]:

$$E_0 = E_d = 78 \cdot A^{1/3}(MeV),$$
$$\sigma_{0int} = 0{,}06\left(NZ/A\right)(1+\alpha) = \left(\pi/2\right)\sigma_0\Gamma_0(b \cdot MeV), \quad (2)$$
$$\Gamma_0 = 3{,}74 + 0{,}69E_d \cdot \beta + 0{,}48\left(E_\sigma^{0+}\right)^{-2}(MeV).$$

Here *A, N, Z* are the atomic mass, the number of protons and the number of neutrons in the nucleus, α is the exchange correction, E_d is the dipole resonance energy, β is the deformation parameter, E_β^{0+} is the energy of the 0^+-th level in the β-vibrating band [9]. The deformation parameters were taken from [10,11]. The Lorentzian parameters derived from relations (2) were corrected, and the correction coefficients were found by normalising the calculated parameters σ_0, Γ_0, E_0 for the ^{138}Ba on their experimental values [12]. This procedure in that case allowed σ_0, Γ_0, E_0 to be obtained with the inaccuracy not exceeding 5%.

The availability of the σ_m, σ_n cross-sections enables the isomeric ratios $R = \sigma_m/(\sigma_m+\sigma_g) = \sigma_m/\sigma_n$ (σ_g being the ground state population cross-section) to be evaluated. In the present work, such valuation was performed at the ~16 MeV energy, i.e. in the region of cross-section maxima where the relative error of determining R ratio is minimal. In thus case the isomeric ratio was determined as that of Lorentzian parameters $R = \sigma_1/\sigma_0$ that approximate the IS excitation cross-sections in the $(\gamma,n)^m$ reactions and the total cross-section of the (γ,n) reactions (Tables 1,2). The following isomeric ratio values at the energy of 16 MeV were obtained: R = 0,27 (^{129}Ba); R = 0,25 (^{131}Ba); R = 0,2 (^{135}Ba); R = 0,14 (^{137}Ba). The estimated IR determination error reaches ~ 15%. It is seen from the above isomeric ratios values that IR decreases with isotope mass: they are maximal for the lightest isotope ^{129}Ba and minimal for ^{137}Ba. Such IR behaviour could be explained within the framework of the statistical mechanism of the isomeric states population in the $(\gamma,n)^m$ reactions, since with the barium isotope mass increase the N=82 neutron shell is filled, the level density decreases [13,14], and, respectively, the isomeric ratio R decreases.

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ІЗОТОПИ БАРІЮ ЯК ОБ'ЄКТИ ДЛЯ ВИВЧЕННЯ ІЗОМЕРНИХ ВІДНОШЕНЬ

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На гальмівному випромінюванні мікротрона М-30 досліджено перерізи збудження ізомерних станів у (γ,n) реакціях для ізотопів барію-(129, 131, 135) в області енергій 8–17 МеВ.