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INVESTIGATION OF THE INTENSITIES OF HARD γ TRANSITIONS IN THE CAPTURE OF RESONANCE NEUTRONS BY Ba^{135}

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The spectra of hard γ quanta with energies lying between 4 and 10 MeV and emitted as a result of 18 to 1500 eV resonance neutrons by Ba^{135} are measured with a single-crystal scintillation spectrometer and a three-dimensional analyzer. An appreciable anomaly is observed in the intensity of the transitions to the ground and first excited levels. The intensities of these two transitions for 11 resonances in Ba^{135} are determined, and possible explanations of the observed anomaly of the 24.5-eV resonance are presented.

WE used the procedure described essentially in[1] to measure the hard γ rays due to the capture of resonant neutrons of Ba^{135} with a single-crystal scintillation spectrometer. The measurements were made with the IBR reactor of the Joint Institute of Nuclear Research with a time resolution 0.4 and 0.12 μsec/m. The three-dimensional spectrum was recorded with a new improved multidimensional analyzer with magnetic tape. We used in our experiments the record of 128 pulse-height and 256 time channels. The measurements were made on samples with cross section areas 120 and 240 cm^2 of barium oxide of natural composition in powdered form. We investigated those resonances which were known to belong to the isotope Ba^{135}. The measurement covered the γ-ray spectrum region from 4 MeV to the neutron binding energy (9.23 MeV).

MEASUREMENT RESULTS

Figure 1 shows the time spectra obtained by us for different γ-ray energies. By way of an example, Fig. 2 shows the renormalized pulse-height spectra for three different resonances of Ba^{135}.

The table lists data on the partial widths Γ_γ^* for the energies 9.23 and 8.40 MeV for 11 resonances. In those cases where the exact value could not be determined, an upper limit is given. The absolute value of Γ_γ^* for the 24.5-eV resonance and for 9.23 MeV energy was determined from the total number of pulses at the total-absorption peak for

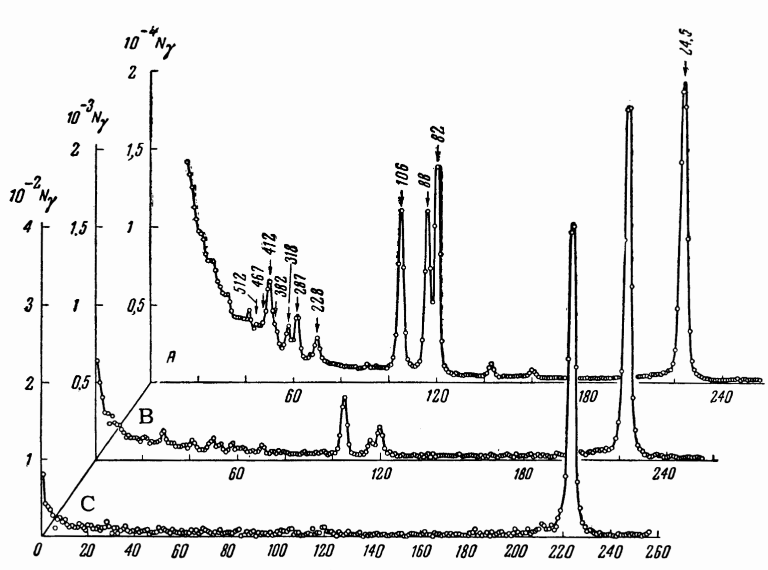

FIG. 1. Time spectra for the capture of neutrons by Ba^{135}: A – spectrum corresponding to the integral amplitude spectrum of the rays with energies from 4 to 10 MeV; B – with energies from 7.3 to 10 MeV; C – spectrum corresponding to a γ-ray energy of 9.23 MeV with amplitude window 500 keV (the peak energies are given in electron volts). The resolution of the neutron spectrometer was 0.12 μsec/m.

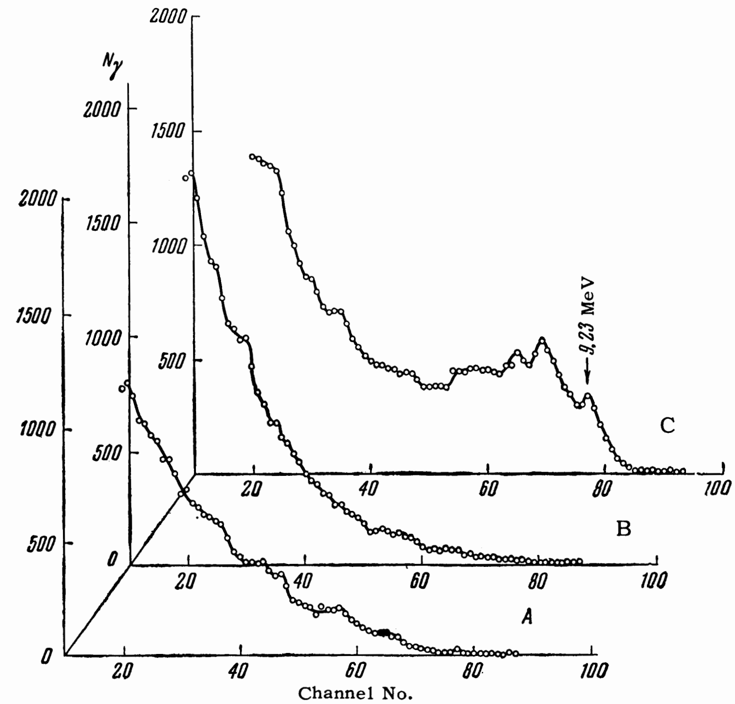

FIG. 2. Amplitude "sections" through the three dimensional spectrum: A – in the 106-eV resonance, B – in the 82-eV resonance, C – in the 24.5-eV resonance.

the 9.23 MeV energy. We used the values of Γ and Γ_n from the Hughes charts[2] supplementing them with data obtained in the measurements of the group of L. B. Pikel'ner (private communication). The product $\Phi_r \Delta\overline{\Omega}$ which is necessary for the calculations was determined experimentally from the capture of neutrons by boron, using the same geometry (Φ_r—neutron flux at the energy of the investigated resonance, $\Delta\overline{\Omega}$—average solid angle in which the γ rays strike the spectrometer crystal). The partial radiation widths $\Gamma^*_{\gamma i}$ for the remaining resonances were calculated from the formula

$$\Gamma_{\gamma i}{}^* = \Gamma_{\gamma 0}{}^* \frac{N_{\gamma i} I_0 \Phi_r(E_0)}{N_{\gamma 0} I_i \Phi_r(E_i)},$$

where $\Gamma^*_{\gamma 0}$ is the partial radiation width for the 24.5-eV resonance, N_γ—the number of pulses in the total absorption peak for the 9.23 MeV energy, I—area of the resonance determined from the parameters given in[2,3], and $\Phi_r(E)$ is the neutron flux at the corresponding resonance energy. The zero subscript pertains to the 24.5-eV resonance, while i pertains to the remaining resonances.

A striking feature of the obtained spectra is the large intensity of the γ transitions to the ground and first-excited levels in the 24.5-eV resonance.

DISCUSSION OF THE RESULTS AND CONCLUSIONS

The ground state level of Ba^{135} has spin 3/2 and positive parity. It follows therefore that the s-neutron is captured into the 1^+ or 2^+ level of Ba^{136}. Inasmuch as the ground level of Ba^{136} has spin and parity 0^+, and the first excited level of vibrational character has spin and parity 2^+ at 830 eV,[3] the γ transitions to the ground and first

Resonances of Ba^{135}

Energy E_n, eV		Γ_n, MeV, from[2]	$E_\gamma = 9.23$ MeV		$E_\gamma = 8.40$ MeV	
From[2]	Our measurements		Γ_γ^*, MeV	$10^2\ \Gamma_\gamma^*/\Gamma_\gamma$	Γ_γ^*, MeV	$10^2\ \Gamma_\gamma^*/\Gamma_\gamma$
24.5	24.5±0,2	9.8	10.5±2.5	9.2	7.5±3	6.5
82	81,9±0.3	165	0.0	0.0	0,2±0.05	0.13
88	88.2±0.3	51	<0.1	<0.07	0.1±0.05	0.07
106 1)	106.3±0.5	150	0,25±0.1	0.17	0,8±0.2	0.55
223	228±1	41	0.3±0.1	0.2	0.4±0.1	0,26
287	290±1	320	<0.2	<0.15	<0.15	<0.1
318	324±2	100	0,3±0.1	0.2	<0.4	<0.25
382	—	260	<0.3	<0.2	—	—
412	—	400	<0.2	<0.15	<0,5	<0.35
467	—	140	<0.5	<0.35	—	—
516	—	130	<0.3	<0,2	—	—
Thermal neutrons		—	—	~0.1	—	~0.1

1) The fraction belonging to the 103-eV resonance of Ba^{136} was not subtracted.

excited levels in Ba^{136} are of type M1 or E2. From the known data[4] on the average values of the partial widths for M1 transitions in this region of nuclei we can expect the intensities of the γ transitions with energy 9.23 and 8.40 MeV to constitute several tenths of one percent per single neutron capture. The intensity of the E2 transitions will even be much smaller. The observed transition intensities for all the investigated resonances, with the exception of 24.5-eV, do not contradict these estimates (see the table). In the capture of thermal neutrons one observes[5] intensities which differ by approximately 0.4% for the two transitions.

Thus, the 24.5-eV resonance is a clear-cut anomaly. The anomaly in the intensity of the transitions at the 24.5-eV resonance cannot be readily reduced to a fluctuation, since the intensity of the transition to the ground state is approximately 40 times the average value for the remaining resonances and the probability of the appearance of such a fluctuation from the Porter-Thomas distribution at $\nu = 1$ is negligibly small: $B(\chi > 40) < 3 \times 10^{-10}$. Simultaneous fluctuation of the partial widths of the two transitions is even less probable.

Let us consider other possible explanations, assuming first that the 24.5-eV resonance is an s-wave resonance.

A. Starting with the notions of Weisskopf (see[6]), the anomalous intensity can be attributed to the fact that a neutron is captured into a purely single-particle or, conversely, purely vibrational level. For such pure transitions we can expect an increase in the matrix elements up to the maximum value given in[6]. However, the observation of such pure levels at excitation energies near 9 MeV has very low probability, and in the region of medium and heavy nuclei not a single case of this kind has yet been observed. In addition, in the case of a purely collective level we can expect a spin 2^+, but in such a case the E2 transition $2^+ \rightarrow 2^+$ remains super-allowed, the intensity of the $2^+ \rightarrow 0^+$ transition being normal or even suppressed (Figure 3).

B. The equality of the intensities of the 9.23 and 8.40-MeV transitions at the 24.5-eV resonance indicates that the spin of this resonance is more likely to be equal to unity. This is due to the fact that the transitions of the type M1 usually have (for not purely collective levels) a greater probability than E2 transitions.

If we assume that the only resonance with spin and parity 1^+ from among those listed in the table is at 24.5 eV, then we can assume that for I = 1 the distance between the levels is much larger than for I = 2. In this case we can expect an increase in the partial radiation width due to the factor D_l/D_0 in

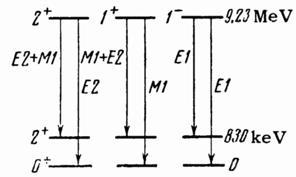

FIG. 3. Possible multipolarities of the transitions at suitable values of the spin and parity in the case of the 24.5-eV resonance.

the formulas for the radiation widths.[6] For the M1 transitions we have

$$\Gamma_\gamma(M1) \sim E_\gamma^3 \bar{D}_l / \bar{D}_0,$$

where E_γ is the energy of the γ quantum; $\bar{D}_l$ and $\bar{D}_0$ are the distances between the levels of the corresponding spin at the capture energy and in the region of the level to which the transition takes place. Contradicting the proposed explanation is the fact, established in the measurements of the Pikel'ner group, that a reduced value of the total radiation width (Γ_γ = 115 MeV) appears in the 24.5-eV resonance, compared with the remaining resonances (Γ_γ = 150 MeV). In addition, the same group measured the spin of the 287-eV resonance and found it to be 1^+.

C. The anomalous intensities of the transitions could be easily attributed to the capture of neutrons into a level with spin 1 and negative parity, i.e., capture of p-neutrons. In such a case both transitions will be of type E1 (Fig. 3). The values of the observed partial widths correspond well to the expected values for E1 transitions. In this case, however, the contradictions are brought about by the large neutron widths of the 24.5-eV level.

The reduced neutron width for p-neutrons in the 24.5-eV resonance assumes a value Γ_{n1} = 27 eV. The average value of the reduced neutron width for the case of 80 neutrons is equal to

$$\bar{\Gamma}_{n1} = 2 \cdot 10^{-4} \bar{D}_I.$$

If we consider the case of a large distance between levels with spin 1^-, say $\bar{D}_{1^-} \approx 10^4$ eV, then $\chi = \Gamma_{n1}/\bar{\Gamma}_{n1} \sim 15$, and the probability of the appearance of such a level at $\nu = 1$ is small: $B(\chi > 15) < 2 \times 10^{-4}$. In addition, in measurements of the total neutron cross sections with a thick sample (the Pikel'ner group) an interference was observed, which can be attributed to interference between the potential and resonant distance. Such a phenomenon contradicts the notion of p-neutron capture.

Complete agreement with the previously obtained experimental facts could be obtained under the assumption that we are dealing here with a phenomenon involving accidental degeneracy of the level with respect to parity. In order to make a final conclusion concerning the nature of the interesting 24.5-eV resonance, the experimental material is still insufficient at present, and therefore experiments are under way for the determination of the multipolarity of the transition and the parity of the given level.

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