Width of giant resonance in the absorption for the cross section of γ rays by nuclei in the region $150 < A < 200$

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We measured the total cross section for the absorption of rays in the region of $E1$ resonance for the nuclei ^{165}Ho, ^{178}Hf, ^{180}Hf, ^{181}Ta, ^{182}W, ^{197}Au, and ^{209}Bi. The singularity in the behavior of the resonance widths, observed in the region $160 < A < 185$, is apparently due to the influence of the neutron subshell $N = 108$.

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Despite the extensive experimental material obtained on the total photoabsorption cross sections by groups working with "monochromatic" γ-ray beams

Nucleus	σ_1 mb	Γ_1 MeV	E_1 MeV	σ_2 mb	Γ_2 MeV	E_2 MeV	$\frac{\sigma_2\Gamma_2}{\sigma_1\Gamma_1}$	Q_0 b	β
Ho-165	235	2.0	12.2	272	4.0	15.5	2.3	6.8±0.8	0.29
Hf-178	291	3.1	12.2	334	4.9	15.5	1.8	7.5±0.8	0.28
Hf-180	286	3.2	12.2	324	5.1	15.3	1.8	7.2±0.8	0.27
Ta-181	272	3.0	12.1	316	5.1	15.0	2.0	6.8±0.8	0.26
W-182	267	3.2	11.9	303	5.6	14.8	2.0	7.2±0.8	0.26
Au-197	535	5.2	13.7	...	...	...	...	...	...
Bi-209	600	4.6	13.8	...	...	...	...	...	...

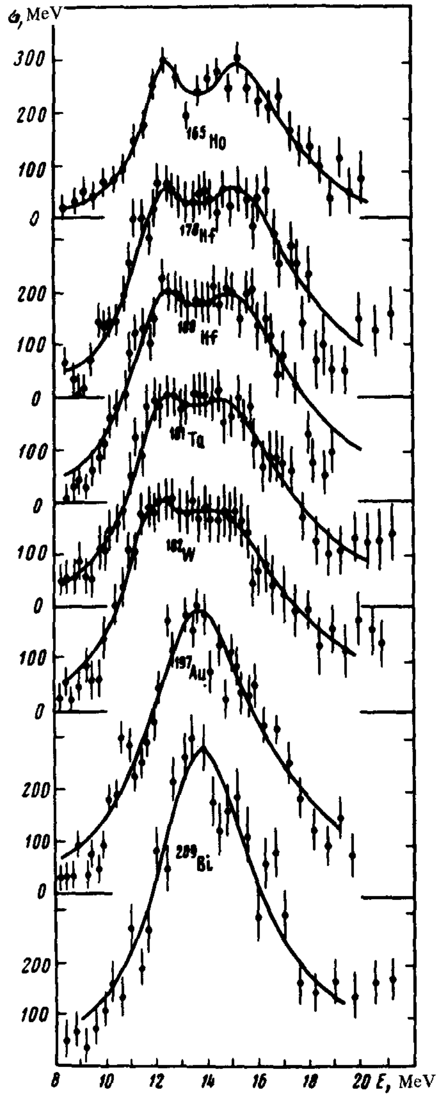

FIG. 1. Total photoabsorption cross sections for the nuclei ^{165}Ho, ^{178}Hf, ^{180}Hf, ^{181}Ta, ^{182}W, ^{197}Au, ^{209}Bi.

at Saclay and Livermore,[1,2] the region of the heaviest nuclei has not been investigated in sufficient detail as yet. We have therefore measured the total cross sections for the absorption of a number of heavy nuclei by the absorption method. The work was performed with the 35-MeV synchroton of our institute. The γ rays were detected with a NaI(Tl) crystal (diameter 15 cm, height 10 cm). The information from the spectroscopic channel was corrected by an in-line computer.[3]

Figure 1 and the table show the plots of the total cross section σ_{tot} and the main parameters of these plots, obtained for the nuclei ^{165}Ho, ^{178}Hf, ^{180}Hf, ^{181}Ta, ^{182}W, ^{197}Au and ^{209}Bi. The parameters of the σ_{tot} curves, measured with the same setup earlier for the nuclei ^{232}Th, ^{235}U, ^{238}U and ^{239}Pu are given in[4].

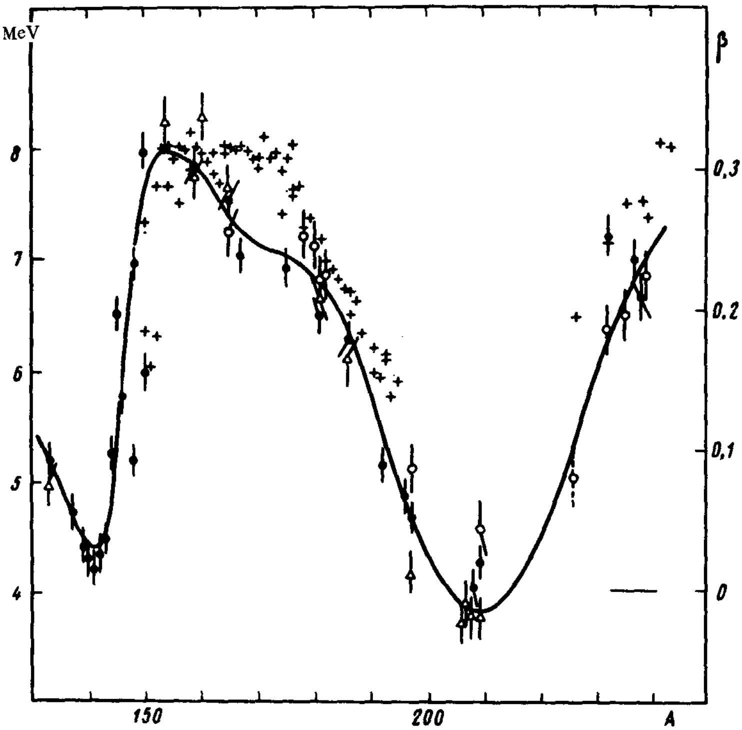

FIG. 2. Widths Γ of $E1$ giant resonance in the region of nuclei with $A > 150$ according to the data of Saclay (●), Livermore (Δ), and the Institute of Nuclear Research of the USSR Academy of Sciences (○). The crosses mark the deformation parameters β.

For the nuclei ^{180}Hf and ^{239}Pu, the total photoabsorption cross section was obtained here for the first time. For ^{178}Hf and ^{182}W there are only data for the photoneutron cross sections, obtained with bremsstrahlung γ rays. The errors listed are mean-squared. The solid lines are the results of the approximation of the cross section plots by Lorentz lines calculated by least squares. For deformed nuclei, the table lists the ratios of the areas under the Lorentz curves $(\sigma_2\Gamma_2/\sigma_1\Gamma_1)$, and also the deformation parameters (β) and the internal quadrupole moments (Q_0) calculated from the obtained experimental data.[5] 1) The presented values of β and Q_0, obtained from the ratios E_2/E_1, agree within the limits of errors with the values of β and Q_0 obtained for the same nuclei by other experimental methods.[6]

Figure 2 shows, as function of the atomic weight A, the widths of the giant resonances for the nuclei with $N > 82$, obtained by us by the absorption method and obtained in Saclay and Livermore[1,2] with "monochromatic" γ-ray beams $\sigma_n = \sigma(\gamma, n) + \sigma(\gamma, pn) + \sigma(\gamma, 2n)$. As is well known, round nuclei with closed shells have single-hump resonances of width $\Gamma = 4$ MeV. For deformed nuclei, the width of the giant resonance should increase above all as a result of the shift of the maxima of the Lorentz curve, this shift being a function of the deformation $(E_2 - E_1) \approx \text{const}(x-1)/A^{1/3}$. Under this assumption, Fig. 2 shows also the values of β. To separate more distinctly the influence of the deformation on the resonance broadening, the scale of β is such that its zero corresponds to $\Gamma = 4$ MeV (round nuclei with $\beta = 0$). The values $\beta = 0.3$ are matched to the $\Gamma = f(A)$ curve in the region $A = 155$. An interesting fact is that starting with $A \sim 160$ and up to $A \sim 185$, the width of the resonances for the nuclei decreases quite sharply in this interval of A in spite of the fact that β remains approximately constant.

In the case of deformed nuclei, the total width Γ of the resonance is approximately equal to the sum $\Gamma_1/2 + \Gamma_2/2 + (E_2 - E_1)$. Therefore, to explain the absence of correlation in the behavior of Γ and β for nuclei in the region $A \sim 160$–185, it must be assumed that the width of the individual Lorentz curves should decrease in this case. Figure 3 shows the widths Γ_1 and Γ_2 for this region of nuclei, based on the results of work with "monochromatic" γ beams obtained in Saclay and Livermore, and also the plot of $(\Gamma_1 + \Gamma_2)/2$ obtained by summing these data.[2] As A increases from 150 to 185, the value of $(\Gamma_1 + \Gamma_2)/2$ actually decreases by an amount on the order of 1 MeV, and this can explain the decrease of the total resonance width observed in this region.

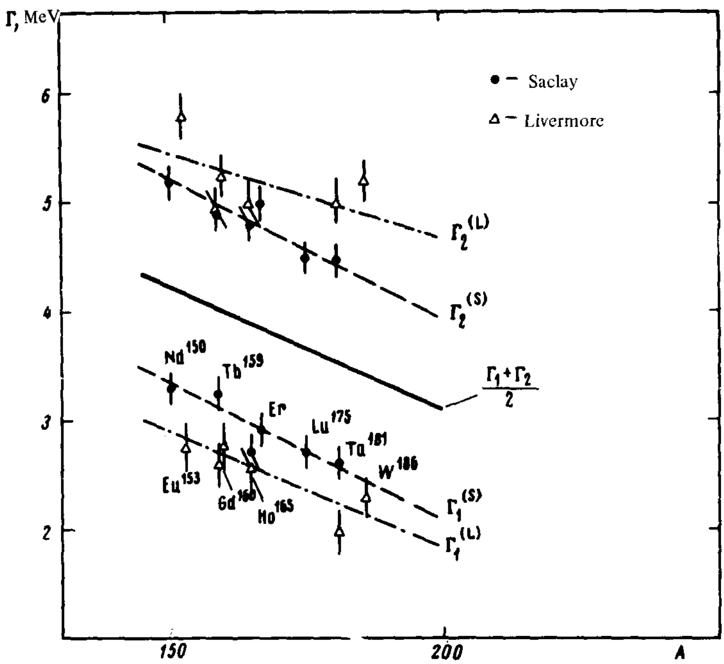

FIG. 3. Width of Lorentz lines approximating the photoabsorption cross sections, for deformed nuclei in the region $150 < A < 185$.

The fact that in the region of nuclei with $A \approx 150$–185 the Lorentz lines become narrower was not discussed in the literature until recently and still remains unexplained. It can be assumed that the reason is the filling of the deformed shell with $N = 108$ neutrons (the nuclei ^{180}Hf, ^{181}Ta, ^{182}Os), the existence of which is presently confirmed by a number of experimental facts based on the analysis of low-energy spectra.[7]

The smaller width observed at the same deformation parameters in the region of nuclei with $A \sim 230-240$ can be attributed at least in part to the dependence of $(E_2 - E_1)$ on $A^{-1/3}$. It is of very great interest, however, to investigate from this point of view nuclei with $A > 240$, where the effect of a deformed shell with $N = 152$ can manifest itself.

[1)] $E_2/E_1 = 0.911x + 0.089$, where x is the ratio of the largest and smallest axes of the nucleus;

$$\beta = \frac{2}{3}\sqrt{\frac{\pi}{5}}\,\frac{(x^2-1)}{x^{2/3}}\,;\quad Q_0 = \frac{3}{5}\sqrt{\frac{5}{\pi}}\,Z r_0^2 A^{2/3}\beta;$$

$r_0 = 1.2$ F.

[2)] The width data obtained by the different groups were systematically displaced in order not to distort the relative course of the curves, and the width values obtained by the total absorption method in a narrower interval of A were not included.

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