Width of $E1$ giant resonance of deformed nuclei in the $150 \leq A \leq 186$ region

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The absorption method is used to measure the total photoabsorption cross section curves for deformed ^{154}Sm, ^{156}Gd, ^{168}Er, ^{174}Yb, ^{184}W, and ^{186}W nuclei in the region of the $E1$ giant resonance. The behavior of the resonance widths for nuclei in the interval $A = 153$ to 186 is discussed.

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We have shown in a recent paper[1] that it follows from the available experimental data on the total nuclear photoabsorption cross section (σ_{tot}) that in the atomic-weight region $\sim 155 < A < \sim 180$ the correlation between the deformation parameter (β) and the width of the $E1$ giant resonance (Γ) is violated. The discrepancy consists in the fact that, starting with $A \sim 155$, the widths of the σ_{tot} curves decreases noticeably whereas the values of β remain practically constant.

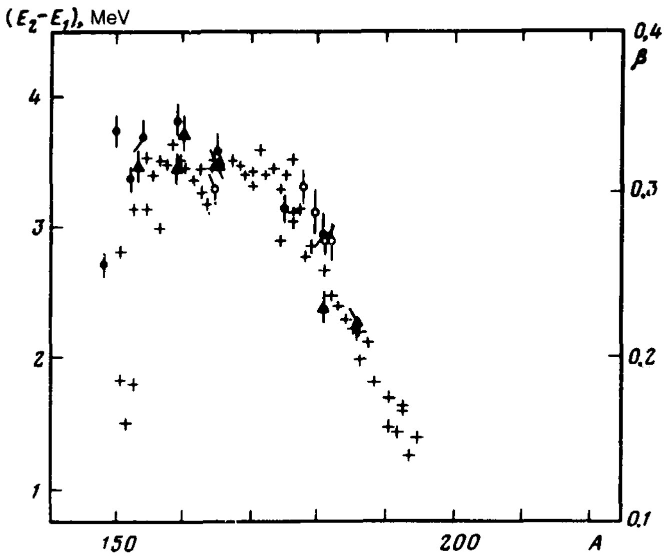

FIG. 1. Difference $E_2 - E_1$ of the resonance energies for deformed nuclei in the region $150 < A < 190$:O—from the data on the σ_{tot} curves measured in[1]; ● and ▲—from the data on the photoneutron cross sections σ_n measured on beams of quasimonochromatic photons by the Saclay and Livermore groups, respectively.[3,4] The crosses mark the deformation parameters β. The values of β equal to 0 and 3 are made to coincide with the values of $(E_2 - E_1)$ in the region of $A \sim 155$.

It is well known[2] that in the case of rigid deformed nuclei, such as the nuclei in the $150<A\leqslant 186$ range, the width of the giant resonance is determined by three parameters: the widths Γ_1 and Γ_2 of the resonances corresponding to oscillations along and across the deformation axis (the axis-length ratio is R) and the distance E_2-E_1 between the maxima of these resonances. The width Γ is approximately equal to the sum $\Gamma_1/2+\Gamma_2/2+(E_2-E_1)$. The quantity (E_2-E_1) should be a function of the deformation of the nucleus

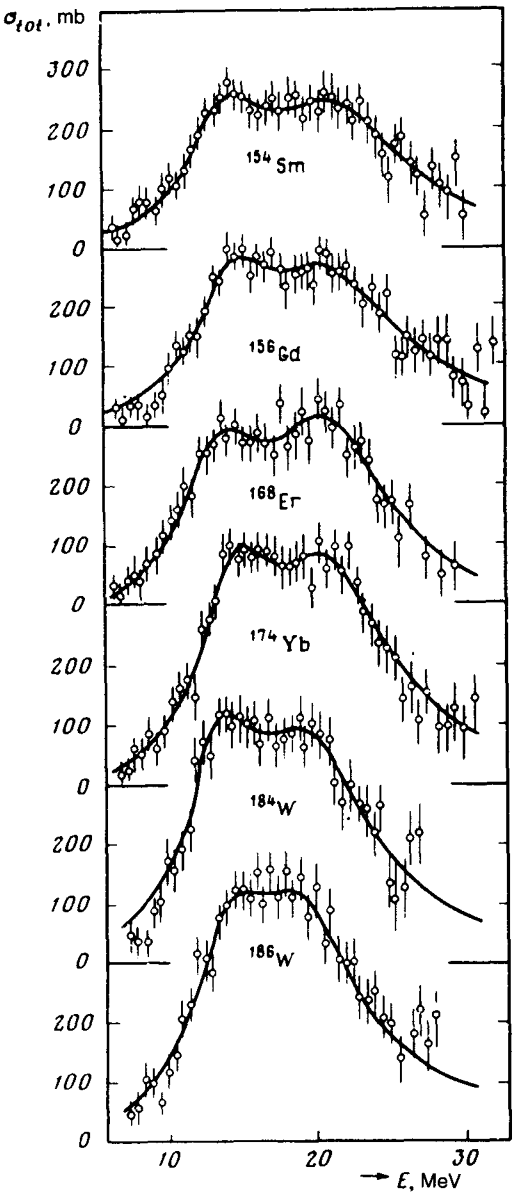

FIG. 2. Total cross sections of the photoabsorption of the nuclei ^{154}Sm, ^{156}Gd, ^{168}Er, ^{174}Yb, ^{184}W, and ^{186}W. The mean squared errors are shown.

$$\left(\frac{E_2}{E_1} \approx R \approx 1+\beta;\, E_2 - E_1 \approx \text{const}\cdot\frac{1}{A^{1/3}} \times \frac{(R-1)}{R^{2/3}} \approx \text{const}\cdot\frac{1}{A^{1/3}}\,\beta\left(1-\frac{2}{3}\beta+\frac{5}{9}\beta^2\right)\sim\frac{1}{A^{1/3}}\cdot 0.85\,\beta\right).$$

As seen from Fig. 1, the experimental values of $(E_2 - E_1)$ for the nuclei in the region $A = 150$–186 correlate well with the behavior of β. Thus, the obtained discrepancy should be due to the behavior of the widths Γ_1 and Γ_2.

The experimental data for the widths Γ_1 and Γ_2 obtained by different workers have systematic deviations. To refine the behavior of Γ_1 and Γ_2 in this region of A under the conditions of a single experiment, we measured additionally the total absorption cross sections for six nuclei: ^{154}Sm, ^{156}Gd, ^{168}Er, ^{174}Yb, ^{184}W, and ^{186}W. Just as in[1], the cross sections σ_{tot} were measured by the total-absorption method. The measurement procedure was described in detail in[5-7]. The obtained absorption cross section curves are shown in Fig. 2. The solid lines are the results of approximating the experimental data with two Lorentz lines. The parameters of these lines [the resonance energies (E_i), the cross sections at the maxima (σ_i), and the widths at half-height (Γ_i)], calculated by least squares, are listed in Table I. Table I gives also the widths Γ of the E 1 resonance[1] obtained from the ratios E_2/E_1, from the values of the internal quadrupole moments of the nuclei (Q_0), and from the deformation parameters β, as well as the sums of the integral cross sections calculated for the Lorentz curves $(\sigma_{0L} = \sigma_{0L_1} = \sigma_{0L_2}$). The average value of the ratios $\sigma\eta_L/0.06\ (ZN/A)$ given in the last column of Table I for the six nuclei is 1.39 ± 0.05. This value agrees well with the theoretical integral cross section σ_0 obtained in[8] provided that the fraction of the exchange forces is $x = 0.5[\sigma_0 = \int_0^\infty \sigma_{tot} dE = 0.06(ZN/A)(1+0.8x)]$.

Figure 3 shows the data for the values of $\Delta\Gamma = [\Gamma - (E_2 - E_1)]$ obtained from the cross sections σ_{tot} measured by the absorption method in[1] and in the present study, as well as from the plots of the photoneutron cross sections $[\sigma_n = \sigma(\gamma,n) + \sigma(\gamma,pn) + \sigma(\gamma 2n)\cdots]$ measured with quasimonochromatic γ beams.[3,4,12] As seen from Fig. 3, when A varies in the range $153 \leqslant A < 175$ the value of $\Delta\Gamma$ decreases noticeably by approximately 0.7 MeV. In this entire interval, β remains practically constant, so that the decrease of $\Delta\Gamma$ can be due only to a corresponding decrease of the widths Γ_1 and Γ_2. This is confirmed by the values of Γ_1 and Γ_2 given in Table I for this region of A

$$\left(\frac{\partial\Gamma_1}{2} + \frac{\partial\Gamma_2}{2} \approx \frac{1.5\ \text{MeV}}{2} = 0.75\ \text{MeV}\right)^3 .$$

The relative decreases of the widths, $\delta\Gamma_1/\Gamma_1$ and $\delta\Gamma_2/\Gamma_2$, are approximately equal at about 20%.

For the nuclei with $A > 175$, the deformation parameters β begin to decrease, and consequently the Lorentz curves come together and overlap more strongly. As a result $\Delta\Gamma$ becomes somewhat smaller than $(\Gamma_1 + \Gamma_2)/2$. The $(\Gamma_1 + \Gamma_2)$ curve shown in the same figure was obtained from the smoothed $\Delta\Gamma$ curve with account taken of this correction. In accord with the data obtained for Γ_1 and Γ_2 in[1] and in the present paper, the $(\Gamma_1 + \Gamma_2)$ curve has a minimum in the $A \sim 175$–180 region.

TABLE I.

Nucleus	E_1 MeV	σ_1 mb	Γ_1 MeV	E_2 MeV	σ_2 mb	Γ_2 MeV	Γ MeV	Q_o b	β	$\sigma_{oL}/0.06\frac{ZN}{A}$
^{154}Sm	12.2	188	3.4	15.7	207	5.7	8.1 ± 0.2	6.3 ± 0.3	0.32 ± 0.02	1.28
^{156}Gd	12.3	206	3.2	15.7	220	5.5	7.7 ± 0.2	6.2 ± 0.3	0.31 ± 0.02	1.30
^{168}Er	11.9	222	3.2	15.5	275	4.5	7.4 ± 0.2	7.5 ± 0.7	0.32 ± 0.03	1.26
^{174}Yb	12.3	297	2.9	15.5	320	4.9	7.1 ± 0.2	7.0 ± 0.6	0.30 ± 0.02	1.52
^{184}W	11.9	315	2.9	14.8	321	4.7	6.8 ± 0.2	7.2 ± 0.8	0.27 ± 0.03	1.50
^{186}W	12.0	246	3.3	14.5	332	5.1	6.4 ± 0.2	6.2 ± 0.8	0.23 ± 0.03	1.48
Average error	±1.3%	± 10.5%	±7.5%	±1.3%	±9.4%	±3.8%	—	—	—	—

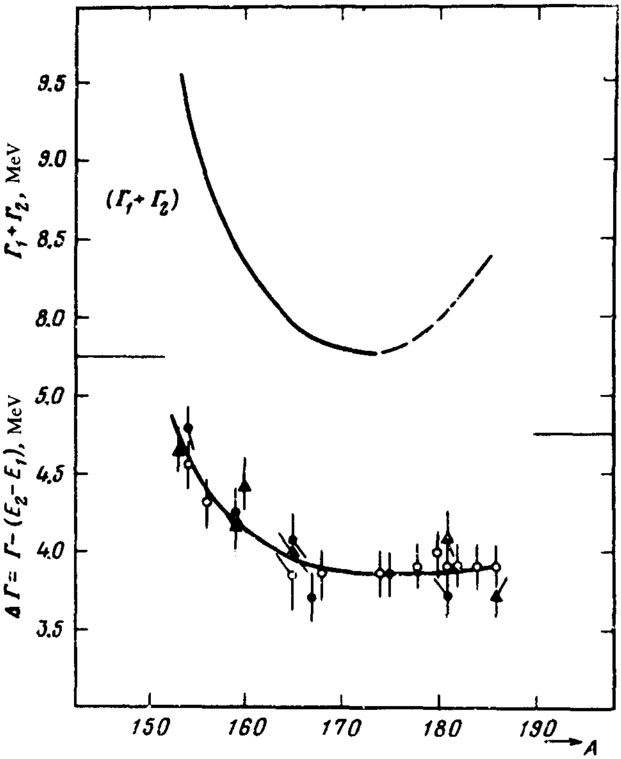

FIG. 3. Experimental values of $\Delta\Gamma = \Gamma - (E_2 - E_1)$ in the region of deformed nuclei with $A = 153$–186: O—present work and[1]; ●—Saclay group; ▲—Livermore group. Owing to a small systematic deviations of the absolute values, the ordinate scales for the Saclay and Livermore data are shifted 0.15 MeV upward and downward, respectively. The $(\Gamma_1 + \Gamma_2)$ curve was obtained from the $\Delta\Gamma$ curve after introduction of corrections in the interval $A = 175$–186.

As already indicated in[1], the observed effect had not been discussed in the literature until recently and has so far no explanation. One of the possible causes of the decrease of the widths Γ_1 and Γ_2 may be the presence, in this region of A, of a subshell with 108 neutrons (the nuclei ^{180}Hf, ^{181}Ta, ^{182}W, and ^{184}Os).[9] The decrease of the widths Γ_1 and Γ_2 in this case would mean a decrease in the number of possible dipole transitions or a large concentration of transitions in the resonance energy region, due to the filling of the deformed subshell $N = 108$. It is interesting to note that it is precisely in that region of A where the correlation between the width of the $E1$ resonance and deformation parameter β is violated that experiments on inelastic scattering of electrons have revealed singularities in the behavior of the charge density inside nuclei (^{166}Er, ^{176}Yb).[10]

[1]The quantity Γ is defined as the width of the $E1$ giant resonance between points whose ordinates constitute half the cross section at the point $\bar{E} = (E_1 + 2E_2)\frac{1}{3}$.

[2]The experimental values of Γ and E_i are determined with higher accuracy than Γ_1 and Γ_2, therefore the values of $\Delta\Gamma$ fit the curve with a smaller scatter.

[3]For the nuclei with $A = 153$–175 (see Table I) the sum $[(\Gamma_1/2 + \Gamma_2/2) + (E_2 - E_1)]$ coincides with the value of Γ within <0.1 MeV.

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