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Correlation of the Partial Radiation and Neutron Widths in the $^{163}Dy(n\gamma)^{164}Dy$ Reaction

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The γ spectra from the $^{163}Dy(n\gamma)^{164}Dy$ reaction are investigated with a Ge(Li) spectrometer. Effects of a nonstatistical nature are observed: correlation between the reduced radiation and neutron widths and between different partial radiation widths. The absolute mean reduced partial width exceeds values based on different models and experimental data for other nuclei. The number of degrees of freedom of the partial width distribution for transitions to the ground-state rotational and γ-vibrational bands is $\nu=2\pm0.5$.

In 1968 we used a scintillation anticoincidence spectrometer to study γ spectra in resonances of the $^{163}Dy(n\gamma)^{164}Dy$ reaction.[1] The partial radiation widths exceeded values calculated on different models, and transitions to the 4^+ level of the ground-state rotational band exhibited correlation with reduced neutron widths. To obtain more precise information about the observed nonstatistical effects we again investigated γ spectra from $^{163}Dy(n\gamma)$ with a Ge(Li) spectrometer, covering the range $E_\gamma = 5.5-8.0$ MeV in resonances with neutrons up to 200 eV.

1. EXPERIMENT

The neutron source was the linear electron accelerator of the I. V. Kurchatov IAE. The 90% enriched ^{163}Dy sample (130 g) was placed 8 m from the accelerator target. The volume of the Ge(Li) detector was 17 cm^3; its effective resolving power for high-energy γ quanta was 23 keV. Two AI-4096 analyzers connected in series formed a multiparameter analyzer. The spectra were investigated simultaneously with 512 amplitude channels in each of 16 time intervals. A stabilization system was provided for the expander and input unit of the analyzer.

The data were processed on TRA and IST-1905 electronic computers. The least squares method was used to obtain a curve that best fitted the experimental double-emission peaks. Calibration was based on known intensities in the thermal neutron region.[2]

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2. RESULTS AND DISCUSSION

In 14 neutron resonances we determined the intensities of electric dipole transitions to 10 intermediate levels. Because transitions to excited 4^+ levels were present (^{163}Dy has spin $5/2^-$), spin 3^- was assigned to ten resonances. The transitions to the ground-state rotational band and the γ-vibrational band were resolved clearly. Our subsequent analysis involved mainly these transitions in resonances having spin 3^-.

The accompanying table gives the intensities of transitions to the ground state rotational and γ-vibrational bands in resonances with spin 3^-. We calculated the mean reduced partial widths for 3^- spin states $\langle \Gamma_{\gamma ij}/E_\gamma^\alpha D\rangle_i[\mathrm{MeV/eV \cdot MeV^\alpha}]$, where D = 13 eV[4] is the separation of 3^- levels, and α equals 3 or 5 (see the figure). The reduced widths averaged over all J = 3^- resonances and final states are compared in the figure with values based on different models. The analysis of these data indicates:

1) The mean reduced widths depend weakly on the final states.

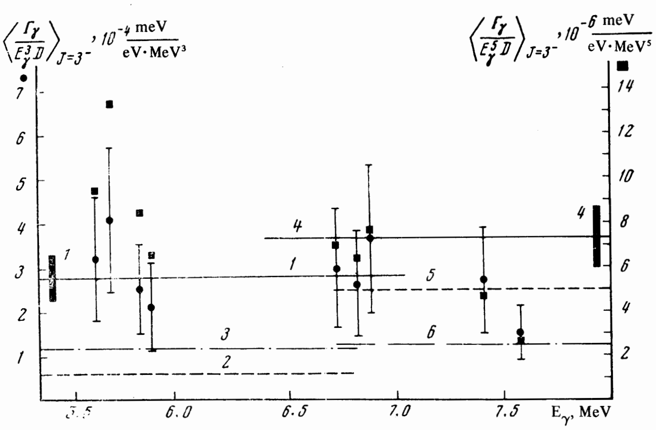
2) The variation of the widths agrees somewhat better with a E_γ^3 law.

3) The mean reduced width to the 916-keV (4^+) level of the γ-vibrational band ($E_\gamma = 6740$ keV) does not differ from the other reduced widths. The absence of a transition in the thermal region[2] is obviously associated with intensity fluctuations of this line in a negative energy resonance[5] and a resonance at 16.2 eV. However the intensities of this 6740-keV γ transition behave strangely: The transition is almost absent in strong resonances with large Γ_n^0 (E_n = 204, 106, 55.8, and

Intensities* of transitions to the ground-state rotational and γ-vibrational bands in resonances with spin 3^-

Γ_n^0, meV [3]	E_n, eV	E_γ, keV				
		7581	7411	6892	6826	6740
4.55 ± 0.2	16.2	0.16 ± 0.04	1.45 ± 0.20	0.63 ± 0.1	0.05	—
0.2 ± 0.02	19.7	0.07 ± 0.07	0.45 ± 0.12	0.22 ± 0.13	0.93 ± 0.17	2.6 ± 0.3
0.41 ± 0.04	50.1	0.3 ± 0.2	0.6 ± 0.2	0.6 ± 0.3	0.8 ± 0.4	2.5 ± 1.0
4.0 ± 0.34	55.8	0.53 ± 0.14	2.2 ± 0.3	2.25 ± 0.30	1.25 ± 0.20	—
0.86 ± 0.17	65.8	1.1 ± 0.2	1.05 ± 0.2	3.6 ± 0.4	0.5 ± 0.25	0.5 ± 0.2
1.2 ± 0.08	93.8	0.5 ± 0.2	0.9 ± 0.3	0.3 ± 0.2	0.7 ± 0.2	1.4 ± 0.3
$9.\pm1.3$	106	0.64 ± 0.18	2.5 ± 0.2	1.65 ± 0.20	2.8 ± 0.2	0.05
3 ± 0.5	126	2.35 ± 0.30	1.45 ± 0.30	1.0 ± 0.4	1.7 ± 0.5	2.1 ± 0.5
5.1 ± 1.2	204	0.3 ± 0.2	0.8 ± 0.3	1.5 ± 0.5	0.4 ± 0.3	0.2

*In number of photons per 100 captures.



Mean reduced partial widths versus γ quantum energy: (1–3) on the statistical model and (4–6) on the giant resonance model. (1, 4) our data; (2, 5) theoretical values; (3, 6) according to Carpenter.

16.2 eV), except in the 126-eV resonance, and has a high intensity in resonances with small Γ_n^0 (E_n = 93.8, 65.8, 50.1, and 19.7 eV):

4) The experimental mean reduced widths for $J = 3^-$ resonances are 2.5 times greater than the values based on different models and also exceed Carpenter's calculations[6] for 12 nuclei (121 transitions). Thus the experimental data in conjunction with the single-particle model for dysprosium give the reduced width

$$\langle \Gamma_{\gamma ij} / E_\gamma^3 D \rangle_{ij} = (2.8 \pm 0.5) \cdot 10^{-4}\,\mathrm{meV/eV \cdot MeV^3},$$

according to the theory, while Carpenter gives (0.6–1.2) $\times 10^{-4}$; on the giant resonance model for dysprosium we obtained

$$\langle \Gamma_{\gamma ij} / E_\gamma^5 D \rangle_{ij} = (7.3 \pm 1.3) \cdot 10^{-6}\,\mathrm{meV/eV \cdot MeV^3},$$

according to the theory, whereas the reduced width given by Carpenter is (5–2.5) $\times 10^{-6}$. The higher intensities can be attributed to single-particle transitions of valence nucleons[7] and to a high value of the s-neutron strength function.[8] The greater reduced widths of the high-energy transitions can account qualitatively for the ~20% increase of the total radiation width of ^{163}Dy in a comparison with the gradual decrease of Γ_γ as a function of the atomic number A.

We observed strong correlation[2)] between the reduced partial radiation and neutron widths for transitions to the 4^+ level of the ground-state rotational band (correlation coefficient $C_{\gamma n} = 0.93$) and to the 3^+ level of the γ-vibrational band ($C_{\gamma n} = 0.7$) with $J = 3^-$. For the transition to the 4^+ level of the γ-vibrational band we have $C_{\gamma n} = -0.7$, which could be expected in accordance with the behavior of the intensities mentioned in item 3) above. The correlation coefficient of the other transitions is about zero.

When we consider the correlation coefficient averaged over transitions to all levels of the rotational and vibrational bands, we find that the dispersion of the coefficient can be represented approximately by $\Delta C = (1 - C^2)/\sqrt{m}$ (where m is the number of cases); the applicability of this formula is indicated by Monte Carlo calculations.[8] for m = 45 we thereby obtain $\langle C_{\gamma n} \rangle = 0.23 \pm 0.14$. If in view of special characteristics exhibited by the intensities of transitions to the 4^+ vibrational level we do not consider these transitions, we obtain $\langle C_{\gamma n} \rangle = 0.45 \pm 0.14$) for m = 36). There is only a very low probability of obtaining this result in the case of two uncorrelated distributions.[8]

A positive correlation exists between the different partial radiation widths of all transitions to the rotational and vibrational bands (omitting the 4^+ level of the vibrational band). We obtain the average correlation coefficient $\langle C_{\gamma\gamma} \rangle = 0.32 \pm 0.12$. This indicates that the same components of highly excited states contribute to the given transitions.

We obtained $\nu = 2 \pm 0.5$ (m = 36) degrees of freedom for the partial width distribution, evaluated by the maximum-likelihood method for transitions in $J = 3^-$ resonances with positive correlation (omitting transitions to the 4^+ level of the γ-vibrational band). The method of Wilets,[10] in which medium and large widths have a decisive role, yields $\nu_W = 3.8 \pm 1.0$.

The observed correlation between $\Gamma_{\gamma\,ij}$ and Γ_n^0, and that between $\Gamma_{\gamma\,ij}$ and $\Gamma_{\gamma ij'}$, for transitions to levels of the ground-state rotational band and the γ-vibrational band are consistent with Lane's original theory of direct and "channel" capture. Correlation can also result from transitions of "valence nucleons" when three-quasiparticle intermediate doorway states are excited.

In the model of Beer,[11] who considered the possibility of narrower distributions of correlated partial widths than with $\nu = 1$, the number of degrees of freedom is associated with the correlation coefficient of the partial radiation and neutron widths and with the number of doorway states that make the main contribution to the given processes. Based on the values of $\langle C_{\gamma n} \rangle$

2) A recent brief communication [9] reported the observation of correlation between partial radiation and neutron widths in the ^{163}Dy(nγ) reaction.

and ν, we calculated for ^{163}Dy a contribution of the order of 30% from a large group of components of highly-excited states, which can be interpreted as single-particle states.[11] The remaining fraction of the intensity of partial transitions results from a group (of about three) doorway states. This result also agrees with Lane's conclusion[12] that the correlation between the widths is determined by the number n of doorway states: $C_{\gamma n} \sim 1/n$. Hence n = 3 for dysprosium.

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