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Nuclear resonance fluorescence in ^{136}Ba

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The resonant scattering of electron bremsstrahlung by an enriched sample of ^{136}Ba has been studied for photon energies of up to 5 MeV. It provided estimates of the radiative widths for 10 levels. Based on the relative yields at scattering angles of 96° and 126°, unambiguous spin assignments were made to 5 of these levels. Where feasible, the yield measurements were supplemented by self-absorption data and by linear polarization studies. For the strongest excitation in ^{136}Ba, at 3.436 MeV, the resonance fluorescence experiments led to a 1^- assignment and a value $\Gamma_0 = 88 \pm 22$ meV for the partial width of the ground state transition. The corresponding $E1$ strength is approximately 1/3 of the $E1$ strengths observed for the strongest low-lying $E1$ transitions in the even-even $N = 82$ nuclei. When combined with previous observations for $N > 82$, the result obtained for ^{136}Ba ($N = 80$) indicates that the strengths of the ground state transitions from the lowest 1^- states peak at $N = 82$. Yield information on a few levels in ^{137}Ba and ^{138}Ba was also obtained.

[NUCLEAR REACTIONS ^{136,137,138}Ba(γ,γ) bremsstrahlung 1.68 MeV $\leq E_e \leq$ 5.0 MeV; measured $\sigma(96°)$ and $\sigma(126°)$, self-absorption, LP; deduced $g\,\Gamma_0^2/\Gamma$, J, π. Enriched ^{136}Ba target, natural target.]

I. INTRODUCTION

Previous studies[1-4] of low-lying ($E_{\text{exc}} < 5$ MeV) $E1$ transitions in even-even rare earth and neighboring nuclei indicated a concentration of $E1$ strength in the ground state transitions from 1^- levels with excitation energies $E(1^-) \approx E(2_1^+) + E(3_1^-)$. The dependence of the strengths of these $E1$ transitions on the neutron number N is shown in Fig. 1. As one proceeds from the deformed region ($N > 88$) towards lower N values, the $B(E1)$ values decrease, reaching a minimum for $N = 86$. However, as N approaches the magic number $N = 82$, the $B(E1)$ values increase again and reach approximately the values observed in the deformed region. For a future interpretation of this behavior it was of interest to know whether the $B(E1)$ values reached at $N = 82$ were maintained for smaller N values of whether the $B(E1)$ values peaked at $N = 82$.

Of the elements Ce, Nd, Sm, and Ba which were known[1-4] to exhibit large $B(E1)$ values at $N = 82$, only Ba had fairly abundant even-A isotopes with $N < 82$. Of these, ^{136}Ba was the most abundant. Moreover, a sizable enriched sample (92.8 g of $Ba(NO_3)_2$, enriched to 65.08% in ^{136}Ba) was available.[6] The fact that no 1^- states at excitation energies below 5 MeV had been reported for ^{136}Ba did not represent a serious obstacle: For $E1$ excitations of the strength observed in the $N = 82$ isotopes, identification as 1^- via angular distribution and linear polarization measurements was quite feasible. On the other hand, the absence, in ^{136}Ba, of excitations sufficiently strong to allow J^π identification would by itself indicate that the $B(E1)$ values were indeed declining for $N < 82$.

Based on these considerations, a study of the reaction ^{136}Ba(γ,γ) for photons below 5 MeV was initiated, and this paper is a report on the procedures used and on the results obtained in this investigation.

II. EXPERIMENTAL PROCEDURES

Bremsstrahlung from a 37-mg/cm^2 gold foil, bombarded with electrons from the Bartol van de

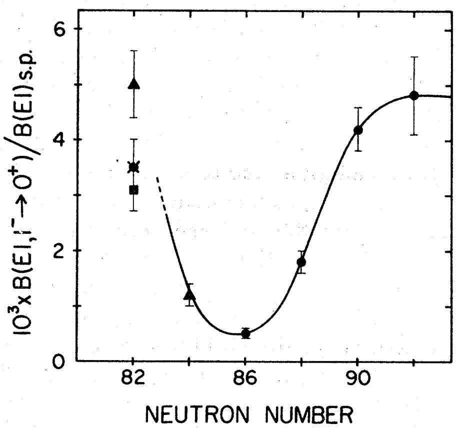

FIG. 1. Trend of the reduced $E1$ transition probabilities for 1^- levels at $E_{\text{exc}} \approx E(2_1^+) + E(3_1^-)$ for the stable even Sm isotopes (Ref. 2) (●), the Nd isotopes ^{142}Nd (Ref. 4) and ^{144}Nd (Ref. 5) (▲), for ^{138}Ba (Ref. 3) (■), and for ^{140}Ce (Ref. 1) (×).

TABLE I. Abundances (%) of the various Ba isotopes in the enriched (^{136}Ba) sample (Ref. 7) and in natural Ba (Ref. 8).

	Barium isotope						
	130	132	134	135	136	137	138
Enriched Ba	...	...	0.2	2.8	65.1	11.9	20.0
Natural Ba	0.1	0.1	2.4	6.5	7.8	11.2	71.9

TABLE II. Spins and widths of ^{136}Ba levels derived from the yields of the reaction ^{136}Ba (γ, γ) at scattering angles of 96° and 126°.

E_{level} (MeV)	$\frac{N(126°)}{N(96°)}$	Spin NRF	Spin Ref. 17	Γ_0^2/Γ (MeV)
1.551	0.6 ± 0.5	1, 2	(2)	(0.7 ± 0.3)/g[a]
2.081	±		(1, 2)	(−0.2 ± 0.7)/g[a]
2.129 (2)	0.44 ± 0.19	2	(1, 2)	0.7 ± 0.2
2.485			(1, 2)	(1.3 ± 3.2)/g[a]
3.044 (2)	1.27 ± 0.14	1	(1, 2)	17 ± 2
3.114 (2)	0.50 ± 0.13	2		4.1 ± 0.6
3.370 (2)	1.18 ± 0.14	1		30 ± 5
3.436 (2)	1.28 ± 0.12	1		71 ± 10
3.981 (2)	1.08 ± 0.25	(1)		21 ± 6
4.137 (3)	1.00 ± 0.43	1, 2		(100 ± 40)/g[a]

[a] $g = (2J_{\text{exc}} + 1)/(2J_{\text{g.s.}} + 1)$.

Graaff accelerator, served as the exciting γ radiation. The scattering geometry, involving a 55-cm^3 Ge(Li) detector at a scattering angle of 96° and a 45-cm^3 Ge(Li) detector at 126°, was identical with the geometry previously used for a nuclear resonance fluorescence (NRF) study of the Sm isotopes and is depicted in Fig. 1 of Ref. 2. To approximately equalize the counting rates in the two detectors, the Pb shielding in front of the 55-cm^3 detector was made thicker, by 0.635 cm, than the Pb shielding in front of the 45-cm^3 detector. The thickness of the Pb between the 55-cm^3 detector and the scatterer was typically 3.81 cm.

The enriched scattering material, 92.8 g of Ba(NO$_3$)$_2$ powder, was contained in a Plexiglas cylinder of 5.72-cm diam and 1.95-cm length. The isotopic composition of the enriched material is listed in Table I. Since the enrichment in ^{136}Ba was not very high, the assignment of observed γ rays to a given Ba isotope was not always unambiguous. Consequently, auxiliary measurements were carried out with Ba of natural composition (see Table I), using a Ba metal disk 1.5 cm thick and 5.0 cm in diameter.

Electron-beam energies ranging from 1.68 to 5 MeV were used for the yield experiments, but were mostly limited to $E_e \leqslant 4.15$ MeV once the absence of strong excitations in ^{136}Ba between 4 and 5 MeV had been established.

With even-even nuclei, only levels having spin 1 or spin 2 can give rise to observable resonant scattering in NRF experiments utilizing bremsstrahlung. Since the scattered radiation was viewed simultaneously by two detectors—at scattering angles of 96° and 126°—and since the angular distributions for spin-1 and spin-2 levels differ drastically, the yield measurements provided spin determinations to the extent to which the statistical accuracy was sufficient (Table II).

The NRF yield for ground-state transitions in even-even nuclei is proportional to $(2J_{\text{exc}} + 1)\,\Gamma_0^2/\Gamma$, where Γ_0 is the radiative width for the ground-state transition, Γ is the total width of the level, and J_{exc} is the spin of the excited state. If this spin is known, the yield measurements provide Γ_0^2/Γ. The final step in obtaining the width Γ_0 then requires knowledge of Γ_0/Γ, the branching ratio for the ground-state transition. For some of the ^{136}Ba levels, such knowledge was available from neutron-capture–γ-ray studies[9,10] and from the disintegration schemes[11,12] of ^{136}Cs and ^{136}La. As expected, the NRF spectra provided limited branching information since the rapid increase in the background counting rate with decreasing γ-ray energy made the observation of cascade γ rays most difficult. Only direct branching to the 2_1^+ state (819 keV) was observable since in this case the background counting rate in the region of the corresponding cascade γ rays was not too severe.

Under favorable circumstances, a self-absorption experiment can be used to determine Γ_0 even if the ratio Γ_0/Γ is not known. In such an experiment, a resonant absorber is placed into the incident beam and the resulting reduction in the NRF yield is determined. Provided $\Delta \gg \Gamma$, the self-absorption is a measure of Γ_0/Δ, where $\Delta = E_\gamma (2kT/Mc^2)^{1/2}$ is the Doppler width of the absorption line. For the self-absorption experiments with ^{136}Ba, the enriched material was approximately evenly divided between the absorber and the scatterer. The absorber contained 10.9 g/cm^2 of enriched Ba(NO$_3$)$_2$ in the path of the incident beam. The scatterer, 5.72 cm in diameter, contained 45.3 g of Ba(NO$_3$)$_2$. To separate resonant from nonresonant effects, a series of runs was carried out in which the Ba(NO$_3$)$_2$ absorber was replaced by a comparison absorber containing Ce$_2$O$_3$. This absorber had been closely matched to the enriched absorber with respect to nonresonant γ absorption with the help of γ lines from radioisotopes. Bombarding energies E_e ranging from 3.3 to 3.8 MeV were used for the self-absorption experiments.

To obtain information concerning the parity of some of the ^{136}Ba levels, in particular of the 3.436-MeV level, another NRF experiment of limited applicability due to low counting rates, the determination of the linear polarization of the resonance radiation, was carried out. For this measurement, the 96° detector was replaced by a two-slab Ge(Li) polarimeter.[13] The two rectangular slabs measured $5.8\times 3.8\times 0.8$ cm^3 and were separated by 2 cm. Use was made of the excellent energy resolution of Ge(Li) and of the sensitivity of slabs to linear polarization.[14]

For further details of the general procedures such as, e.g., the calibration of the γ flux, the reader is referred to previous publications.[5,15]

III. RESULTS AND DISCUSSION

A. Spectra, yields

In Fig. 2, the pulse-height distributions for the region comprising the strongest excitation observed below 5 MeV with the enriched scatterer are shown for the scatterer enriched in ^{136}Ba (top) and for the natural Ba scatterer (bottom). The sums of the 96° and 126° data are plotted. Since, with the exception of ^{136}Ba, the natural scatterer contained more nuclei of the various Ba isotopes than did the enriched scatterer, the 3.436-MeV γ line must be attributed to ^{136}Ba.

The intensity ratio for the 3.339-MeV peaks in the two spectra of Fig. 2 is consistent with the assignment[3] of the 3.339-MeV line to ^{138}Ba. For the 3.37-MeV line, the peak height in the ^{136}Ba spectrum is not reduced as much as it should be if the line originated solely from ^{138}Ba. Instead of a single level in ^{138}Ba,[3] the existence of a doublet has to be assumed, with the lower energy component (3.367 MeV) attributed to ^{138}Ba, and the 3.370-MeV line assigned to ^{136}Ba.

The weak 3.450-MeV line is attributed to the ^{56}Fe in the structural material of the laboratory although assignment to ^{137}Ba cannot be completely ruled out. For a ^{137}Ba level, the peak height in the natural Ba spectrum is expected to be approximately twice the peak height in the ^{136}Ba spectrum. A strong 3.449-MeV excitation had been observed[16] in the reaction ^{56}Fe(γ,γ).

In Fig. 3, the γ-ray spectra in the vicinity of 3.1 MeV are shown for the two scatterers. Again, the sums of the 96° and 126° data are plotted. In addition to the 3.044- and 3.114-MeV lines belonging to ^{136}Ba, the 3.088-MeV line from ^{13}C is observed. The 3.072-MeV line is attributed to ^{137}Ba.

The two spectra displayed in Fig. 4 are only compatible with the assignment of the 3.981- and 4.137-MeV γ rays to ^{136}Ba. They, furthermore, emphasize the strength of the 4.027-MeV excitation in the

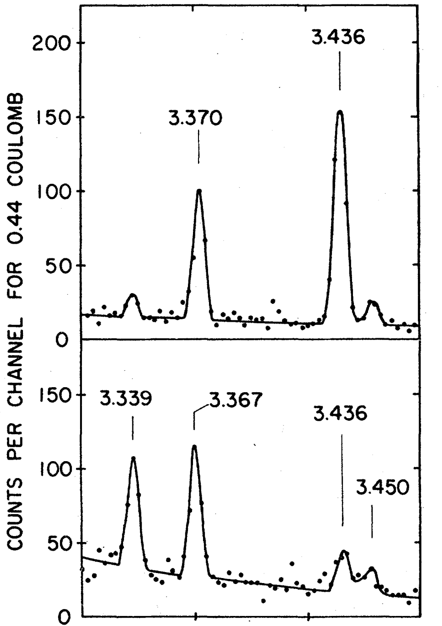

FIG. 2. Sum of the 96° and 126° γ-ray spectra observed between 3.3 and 3.5 MeV with Ba enriched in ^{136}Ba (top) and with natural Ba (bottom) at a bombarding energy of 3.5 MeV.

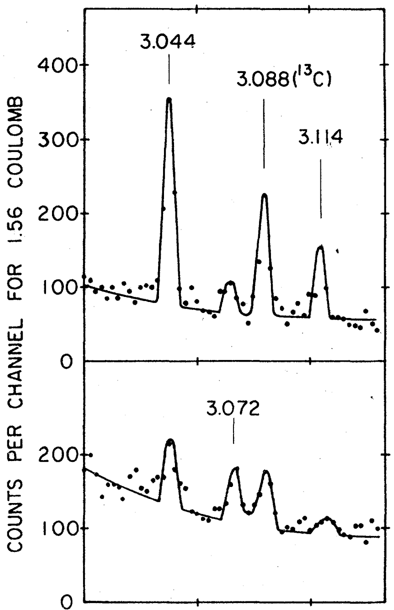

FIG. 3. Sum of the 96° and 126° γ-ray spectra observed between 3 and 3.2 MeV with Ba enriched in ^{136}Ba (top) and with natural Ba (bottom) at a bombarding energy at 3.3 MeV.

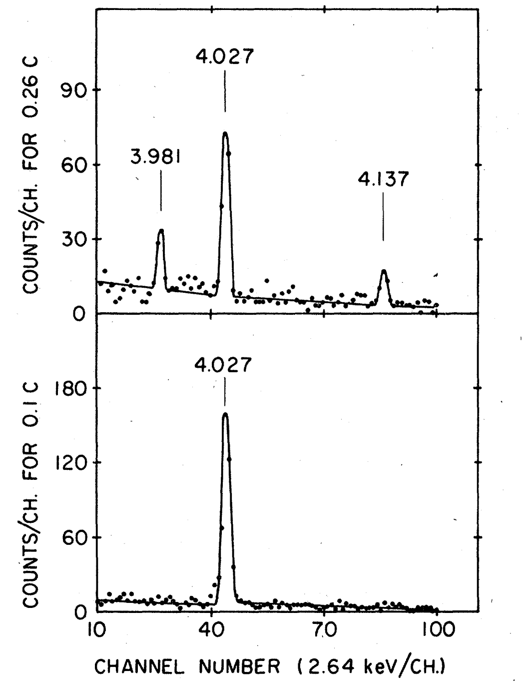

FIG. 4. Sum of the 96° and 126° γ-ray spectra observed between 3.9 and 4.2 MeV with Ba enriched in ^{136}Ba (top) and with natural Ba (bottom) at $E_e = 4.15$ MeV. Note that the two pulse height distributions correspond to exposures differing by a factor of 2.6.

$N = 82$ nucleus ^{138}Ba.

In Table II are listed all the ^{136}Ba levels below 4.2 MeV for which resonant scattering has been observed with bremsstrahlung of endpoint energy ≤ 5 MeV. In addition, those spin-1 and spin-2 levels reported in Ref. 17, which were not observed or only marginally observed in the present NRF experiments, have been listed. Above 4.2-MeV excitation energy, several weak lines, which might have originated from ^{136}Ba, were observed, but the statistics was such that neither their existence nor the assignment to ^{136}Ba were beyond reasonable doubt.

For the levels clearly excited by photons, the energies deduced from the NRF data are listed in column 1 of Table II, with the uncertainty in units of the last digit shown in parentheses. For the other levels, the energies were taken from Ref. 17.

In column 2 of Table II are listed the ratios of the 126° and 96° counting rates. Under the conditions of the experiments, the ratio $N(126°)/N(96°)$ was expected to take on the value 1.20 for spin-1 levels, and the value 0.44 for spin-2 levels. The spins deduced from the observed ratios are given in column 3. Parentheses indicate that the particular spin value could not be unambiguously ($\geq 99.9\%$ confidence level) established by the NRF data, but was favored by better than 6:1. As has been mentioned before, the mere observation of resonant scattering from a given level in an even-even nucleus narrows down the choice of spins to the values 1 and 2.

In the last column of Table II are listed the Γ_0^2/Γ values extracted from the absolute yields. For the spin-1 levels in ^{136}Ba, these Γ_0^2/Γ values are much smaller than the largest Γ_0 values measured[1-4] at $N = 82$. However, the difference could be made up if the ^{136}Ba levels exhibited considerable cascading, i.e., if the Γ_0/Γ ratios were $\ll 1$. The question whether the $B(E1)$ values peak at $N = 82$ or simply reach a plateau which continues below $N = 82$ thus depends importantly on the branching characteristics of the 1^- levels in ^{136}Ba.

B. Branching, self-absorption

For the five possible 1^- levels which were seen in the present NRF study of ^{136}Ba, the only branching information provided by other investigations was evidence[9] for a cascade transition from the 3.044-MeV level to the 0.819-MeV 2_1^+ state. However, a quantitative estimate of the strength of this branch could not be made because the cascade transition coincided in energy with the hydrogen capture γ ray.[9]

The $3.044 \rightarrow 0.819$ cascade γ ray was indeed seen in the NRF spectra and was found to amount to $(32 \pm 16)\%$ of the ground state transition. This led to a ground-state branching ratio $\Gamma_0/\Gamma = 0.76 \pm 0.10$ for the 3.044-MeV level if one assumed that no other cascades originated from it.

For the 3.436-MeV level, the NRF data yielded a ratio $\Gamma_1/\Gamma_0 = (-2 \pm 8)\%$ where Γ_1 is the partial width for the decay to the 2_1^+ level. Assuming the absence of branching to higher excited states, this led to $\Gamma_0/\Gamma = 1.0 \pm 0.1$.

Some of the NRF spectra involving the 3.370-MeV transition indicated branching to the 2_1^+ level. If branching to higher excited states is excluded, the available information is consistent with $\Gamma_0/\Gamma = 0.9 \pm 0.1$.

While the spectra provide branching information piecemeal, the self-absorption results may be

TABLE III. Self-absorption by 10.9 g/cm^2 of enriched Ba(NO$_3$)$_2$.

E_{level}	N (res. absorber) / N (comparison abs.)	Γ_0 (meV)
3.044	0.97 ± 0.11	7 ± 30
3.370	0.96 ± 0.12	13 ± 45
3.436	0.78 ± 0.05	88 ± 20

TABLE IV. ^{136}Ba: Results of the experiments using the Ge (Li) polarimeter.

E_γ (MeV)	$100 \times \frac{N_\parallel - N_\perp}{N_\parallel + N_\perp}$	Multipole character	J_{exc}
3.044	+8.5 ± 14.3	$E1, M1$	$1^{\pm}$
3.436	+6.6 ± 3.2	$E1$	1^{-}

looked upon as providing "global" branching information when combined with the $\Gamma_0{}^2/\Gamma$ values deduced from the yields. In Table III, the results of the self-absorption experiments with ^{136}Ba are summarized. Comparison of these results with the $\Gamma_0{}^2/\Gamma$ values in Table II does not indicate the need to assume branching beyond that deduced from the spectra.

C. Linear polarization, parities

The results of the linear polarization experiments are summarized in Table IV. If $N_\parallel$ stands for the full-energy-peak counting rate with the Ge(Li) slabs in the scattering plane, and if $N_\perp$ denotes the counting rate observed with the slabs perpendicular to that plane, the sign of the expression $(N_\parallel - N_\perp)/(N_\parallel + N_\perp)$ indicates whether the transition from a spin-1 state is $E1$ (+sign) or $M1$ (− sign). From our experience, the ratio is +4.3% for a 3.4-MeV $E1$ transition, and −5.4% for a 3.4-MeV $M1$ transition. The sensitivity increases with decreasing γ energy.

D. Remarks on individual ^{136}Ba levels

1. Level at 1.551 MeV

For this level, which probably is the two-phonon 2^+ state, the mean ground-state branching ratio is[9,11,12] $\Gamma_0/\Gamma = 0.49 \pm 0.04$. With this and the $\Gamma_0{}^2/\Gamma$ value from Table II, the partial width is $\Gamma_0 = 0.29 \pm 0.13$ meV. This corresponds to approximately 1 $E2$ single particle unit (spu).

2. Level at 2.081 MeV

The mean ground-state branching ratio[9,12] is $\Gamma_0/\Gamma = 0.40 \pm 0.03$. Assuming a 2^+ assignment,[12] the NRF experiment leads to a partial width $\Gamma_0 = (-0.1 \pm 0.4)$ meV. The $E2$ spu corresponds to a width of 1.34 meV.

3. Level at 2.129 MeV

The NRF data rule out the 1^+ assignment tentatively proposed in Ref. 12.

With the mean ground-state branching ratio[9,12] of $\Gamma_0/\Gamma = 0.32 \pm 0.02$, the partial width Γ_0 becomes $\Gamma_0 = 2.2 \pm 0.7$ meV. This corresponds to more than 100 $M2$ spu. A 2^- assignment to the 2.129-MeV level is thus ruled out, and 2^+ is left as the only assignment consistent with the NRF data. The observed width corresponds to $\simeq 1.5$ $E2$ spu. The partial width for the 1.31-MeV cascade transition to the 0.819-MeV 2_{I}^{+} level, $\Gamma_1 = 4.66 \pm 1.5$ meV, corresponds to ≈ 35 $E2$ spu and suggests some $M1$ admixture in the cascade transition.

4. Level at 2.485 MeV

The NRF experiments did not provide any evidence that this level was being excited. However, it should be pointed out that the small ground-state branching ratio[12] $\Gamma_0/\Gamma = 0.19 \pm 0.04$ renders the NRF measurement rather insensitive.

5. Level at 3.044 MeV

The linear polarization experiments slightly favor negative parity for this level. The excitation energy amounts to $\approx 91\%$ of the sum (3.351 MeV) of the 2_{I}^{+} (0.819 MeV) and 3_{I}^{-} (2.532 MeV) excitation energies. This is close to the values observed for the 1^- states in the $N = 82$, 84, 86 nuclei. The 3.044-MeV level thus could be the low-lying $[2_{\mathrm{I}}^{+} \otimes 3_{\mathrm{I}}^{-}]$ 1^- level that should be compared with the 1^- levels in the $N = 82$ nuclei.

The self-absorption result did not suggest the existence of additonal branching beyond that observed in the NRF spectra. With $\Gamma_0/\Gamma = 0.76 \pm 0.10$, the partial width Γ_0 becomes $\Gamma_0 = 22 \pm 4$ meV. This corresponds to $\approx 4 \times 10^{-4}$ $E1$ spu and amounts to approximately $\frac{1}{8}$ of the $E1$ strengths observed at $N = 82$.

6. Level at 3.114 MeV

The only assignment compatible with all the NRF data is 2^+. If Γ_0/Γ is unity—no evidence for branching to excited states was obtained—the width for $E2$ transition to the ground state is $\Gamma_0 = 4.1 \pm 0.6$ meV, corresponding to 0.4 $E2$ spu.

7. Level at 3.370 MeV

This spin-1 level is another candidate for being the $[2_{\mathrm{I}}^{+} \otimes 3_{\mathrm{I}}^{-}]$ 1^- state. The excitation energy is almost exactly equal to the sum of the excitation energies of the 2_{I}^{+} and 3_{I}^{-} levels.

With $\Gamma_0/\Gamma = 0.9 \pm 0.1$ (see Sec. III B), the partial width Γ_0 becomes $\Gamma_0 = 33 \pm 7$ meV. This is certainly consistent with the self-absorption result (13 ± 45 meV). Should the 3.370-MeV level indeed be a 1^- excitation, the measured width would correspond to 5×10^{-4} $E1$ spu, i.e., to $\approx \frac{1}{7}$ of the strengths found at $N = 82$.

8. Level at 3.436 MeV

For this, the strongest excitation in ^{136}Ba below 5 MeV, the NRF experiments have reliably established the spin-parity as 1^-. Following the trend in ^{138}Ba and in the rare earths up to at least $N=94$, one is inclined to identify the 3.436-MeV level with the $[2_1^+ \otimes 3_1^-]$ 1^- state although the excitation energy slightly exceeds the sum of the excitation energies of the 2_1^+ and 3_1^- levels.

With the branching ratio arrived at in Sec. III B, the yield data lead to a width $\Gamma_0 = 71 \pm 13$ meV, in fairly good agreement with the self-absorption result $\Gamma_0 = 88 \pm 20$ meV. Since the sensitivity of the NRF spectra to branching is poor, the self-absorption value is considered more reliable and will be adopted for the time being. The width of 88 meV corresponds to 1.2×10^{-3} $E1$ spu and amounts to $\approx \frac{1}{3}$ of the strengths observed at $N=82$ (see Fig. 1).

Aside from the 3.044-, 3.370-, and 3.436-MeV levels, the NRF experiments did not excite any other level that could qualify as the two-phonon $[2_1^+ \times 3_1^-]$ 1^- state. Thus, irrespective of which of the three levels is the proper 1^- state, the strength of that state in ^{136}Ba is much below the $E1$ strengths observed at $N=82$, but is comparable with the strength at $N=84$. The measurements with ^{136}Ba thus strongly indicate that the $B(E1)$ values reached at $N=82$ represent a peak which interrupts the fairly rapid falloff which accompanies the transition from the deformed region ($N>88$) to the "spherical" region ($N<88$).

E. Remarks on levels in other Ba isotopes

1. Level in ^{137}Ba at 3.072 MeV

The relative yields of 3.072-MeV γ rays observed (see Fig. 3) with the natural Ba scatterer and with the enriched scatterer are consistent with the assignment of this γ ray to ^{137}Ba. No other Ba isotope would give rise to a comparable yield ratio.

The 3.072-MeV γ ray was not observed in any other (γ, γ) study carried out at this laboratory and thus is not likely to be attributable to resonant scattering from building, shielding, or container materials as is, e.g., the 3.088-MeV line (^{13}C).

With ^{137}Ba as the assumed source of the 3.072-MeV radiation, a width $g\Gamma_0^2/\Gamma$ of 40 ± 10 meV is obtained.

2. Levels in ^{138}Ba

Although their main purpose had been to help with the assignments of the γ rays from the enriched scatterer to the various Ba isotopes, the data obtained with natural Ba were of sufficient statistical accuracy to represent a meaningful supplement to the existing NRF data[3] on ^{138}Ba.

TABLE V. Widths of ^{138}Ba levels derived from the yields of the reaction ^{138}Ba (γ, γ) at scattering angles of 96° and 126°.

E_{level} (MeV)	Γ_0^2/Γ (meV) Ref. 3	 Present work
2.640	2.9 ± 1.1	1.1 ± 0.3
3.339	12.3 ± 1.4	9.4 ± 1.5
3.367	10.9 ± 1.2^{a}	6.5 ± 1.2^{a}
4.027	206 ± 10	270 ± 30

[a] After subtraction of a 25% contribution from the 3.370-MeV level in ^{136}Ba.

In Table V, the widths based on the present studies are compared with the results reported in Ref. 3.

For the weakly excited 2.640-MeV 2^+ level, the result of the present study brings the $E2$ strength for the ground state transition closer to the isoscalar value[18] and closer to the theoretical estimate by Waroquier and Heyde[19] than was indicated by the nominal value reported in Ref. 3.

For the 4.027-MeV level, the self-absorption result $\Gamma_0 = 0.36$ eV (Ref. 3) was used to correct the yields, observed in the present study, for the resonant attenuation of the incident beam within the scatterer. In comparing the widths listed in Table V for the 4.027-MeV transition, it should be noted that the error quoted in Ref. 3 must be a partial error only since the uncertainty in the flux standard alone was 7% (p. 1970 of Ref. 3). Moreover, the uncertainty in the standard did not include any allowance for the possibility that the branching ratio of the standard level might be smaller than unity.

The Γ_0^2/Γ value determined in the present study requires considerably less (if any) branching from the 4.027-MeV level to ^{138}Ba levels above the 2_1^+ level (1.436 MeV) than does the Γ_0^2/Γ value reported in Ref. 3. Considering the paucity of excited states in ^{138}Ba suitable for population from a 1^- level and the strength of the ground-state transition with which cascade γ rays would have to compete, the branching ratio $\Gamma_0/\Gamma = 0.58$ reported in Ref. 3 was surprisingly low.

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