PHYSICAL REVIEW C VOLUME 18, NUMBER 4 OCTOBER 1978

Nuclear resonance fluorescence in ^{142}Nd

F. R. Metzger

Bartol Research Foundation of The Franklin Institute, University of Delaware, Newark, Delaware 19711

(Received 22 May 1978)

The resonant scattering of electron bremsstrahlung by an enriched sample of ^{142}Nd has been studied for photon energies of up to 5 MeV. It provides estimates of the radiative widths for 13 levels. Based on the relative yields at scattering angles of 96° and 126°, unambiguous spin assignments were made to 6 of these levels. Where feasible, the yield measurements were supplemented by self-absorption data and by linear polarization studies. For the strongest excitation, at 3.425 MeV, the resonance fluorescence experiments led to its identification as a 1^- state with a radiative width $\Gamma_0 = 370 \pm 45$ MeV. The corresponding $E1$ strength is comparable to the $E1$ strengths measured in other even-even $N = 82$ nuclei for the 1^- member of the quintuplet arising from the coupling of the lowest octupole vibration to the 2_1^+ level. The sum of the excitation energies of the 2_1^+ state and the 3_1^- state in ^{142}Nd is consistent with such an interpretation of the 3.425-MeV level.

[NUCLEAR REACTIONS ^{142}Nd(γ,γ), bremsstrahlung 1.85 MeV $\leq E_e \leq$ 5.0 MeV; measured σ(96°) and σ(126°), self-absorption, linear polarization; deduced $g\Gamma_0^2/\Gamma$, J, π. Enriched target.]

I. INTRODUCTION

Once it had been established[1] that linear polarization measurements at γ-ray energies below 2 MeV were feasible under the adverse conditions of nuclear resonance fluorescence (NRF) experiments utilizing bremsstrahlung, the extension of the technique to higher energy γ rays was the next challenge.

In a study of ^{140}Ce, a strong excitation was observed[2] at 3.644 MeV and was identified as an electric dipole with the aid of a two-Ge(Li)-slab polarimeter. The ground-state transition from the 3.644-MeV level in this $N=82$ nucleus turned out to be considerably stronger than expected on the basis of the experimental evidence[3,4] for other $N<88$ rare earth isotopes and of a theoretical estimate[5] which made one expect a decrease in the $B(E1)$'s as one moved away from the deformed region ($N>88$) towards the magic neutron number $N=82$.

The measurements in ^{140}Ce indicated that a considerable concentration of $E1$ strength occurred in the 1^- state located at an excitation energy which was approximately the sum of the excitation energies of the 2_1^+ and 3_1^- states. This made an extension of the NRF measurements to ^{142}Nd highly desirable, especially since a study[6,7] of the reaction ^{142}Nd (p,p') had revealed the existence of several 1^- states in ^{142}Nd below 5 MeV excitation energy.

This paper is a report on the NRF studies carried out using an enriched sample[8] of ^{142}Nd. Some preliminary results have been reported previously[9] and were incorporated in another attempt[10] to shed some light on the systematic behavior of low-lying $E1$ transitions in the rare earths.

II. EXPERIMENTAL PROCEDURES

Bremsstrahlung from a 37-mg/cm^2 gold foil, bombarded with electrons from the Bartol Van de Graaff accelerator, served as the exciting γ radiation. For the initial experiments, a 30-cm^3 Ge(Li) detector was used at a mean scattering angle of 96° and a 45-cm^3 Ge(Li) detector at 126°. Later on, the 30-cm^3 detector was replaced by a 55-cm^3 Ge(Li) detector. The geometry then became identical with the one depicted in Fig. 1 of Ref. 11. The scattering material, 79.5 g of Nd_2O_3, enriched to 96.24% in ^{142}Nd, was contained in a Plexiglas cylinder of 5.72 cm inside diameter and 2.58 cm length.

With even-even nuclei, only levels having spin

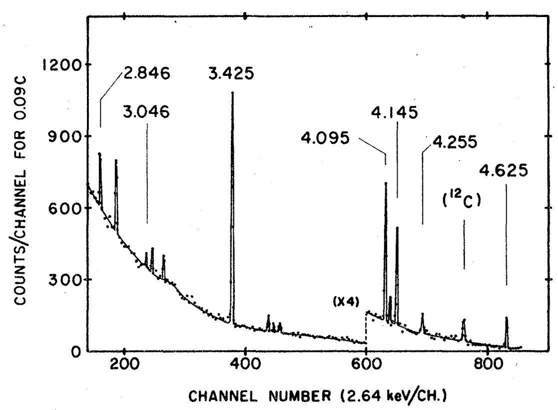

FIG. 1. Sum of the γ-ray spectra from the reaction ^{142}Nd(γ,γ), observed at scattering angles of 96° and 126° with 55-cm^3 and 45-cm^{3}Ge(Li) detectors, respectively. The bombarding energy was $E_e=4.8$ MeV. To simplify the plotting, points between peaks are 10.6 keV apart and represent the averages of four channels. Only full-energy peaks are labeled.

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 (see Table I).

The NRF yield for ground-state transitions in even-even nuclei is proportional to $(2J_{exc}+1) \times \Gamma_0^2/\Gamma$, 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 ^{142}Nd, the branching from some of the levels below 3.4 MeV was known from studies[6] of the decay scheme of ^{142}Pm. Above 3.4 MeV, no branching information was available. It is difficult to extract such information from the γ spectra observed in NRF experiments utilizing bremsstrahlung because the background counting rate at the position of the cascade transitions exceeds, in general, the background counting rate at the position of the ground-state transition by several orders of magnitude (see, e.g., Fig. 1). In the case of ^{142}Nd, no γ lines indicating branching to excited states were observed in the NRF spectra, and only rather rough limits for cascade transitions to the 1.576-MeV 2_1^+ state could be arrived at.

TABLE I. Spins and widths of ^{142}Nd levels, deduced from the yields of the reaction ^{142}Nd(γ,γ) at scattering angles of 96° and 126°. Standard deviations are listed throughout.

E_{level} (MeV)	$N(126°)/N(96°)$	Spin	Γ_0^2/Γ (meV)
1.576 (2)	0.45 ± 0.05	2	4.0 ± 0.3
2.385 (2)	0.52 ± 0.10	2	2.4 ± 0.4
2.583	···	1[a]	0.6 ± 0.7
2.846 (2)	0.40 ± 0.06	2	11.5 ± 1.0
3.046 (2)	0.34 ± 0.36	(2)	1.4 ± 0.6
3.128	···	1,2[b]	0.6 ± 0.9[c]
3.358	···	1,2[b]	0.1 ± 1.0[c]
3.425 (2)	1.19 ± 0.07	1	330 ± 40
4.095 (2)	1.20 ± 0.11	1	110 ± 20
4.145 (2)	1.09 ± 0.13	1	85 ± 15
4.255 (4)	1.5 ± 0.8	1,2	20 ± 7[c]
4.625 (3)	1.10 ± 0.24	(1)	100 ± 20
4.901 (3)	···	1,2	80 ± 30[c]

[a]See Ref. 15.

[b]According to Ref. 6.

[c]A spin of 1 (g = 3) was assumed in calculating this width.

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. Despite the fact that they make possible direct determinations of Γ_0, self-absorption experiments are usually not the first choice (over yield measurements) because they depend on differences of already small counting rates and are thus saddled with large statistical uncertainties for all but the strongest excitations. Nevertheless, considering the lack of branching information for levels above 3.4 MeV, it was felt that a self-absorption study of the 3.425-, 4.095-, and 4.145-MeV levels in ^{142}Nd was justified. The fairly high natural abundance of ^{142}Nd (27.3%) made it feasible to use natural Nd metal as the absorber material and to continue using the enriched scatterer previously employed for the yield measurements. Two slabs of Nd metal, representing 11.87 g/cm^2 of Nd, were placed into the path of the incident beam. To separate resonant from nonresonant effects, a series of runs was carried out in which the Nd absorber was replaced by a comparison absorber of Ce metal. This absorber had been closely matched to the Nd absorber with respect to nonresonant γ absorption with the help of γ lines from radioisotopes. Bombarding energies E_e of 3.63 and 4.50 MeV were used for the self-absorption experiments.

To obtain information concerning the parities of the three strongest levels mentioned above, linear polarization measurements were carried out. For these measurements the 96° detector was replaced by a two-slab Ge(Li) polarimeter.[1] 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.[12] The polarization studies were carried out at bombarding energies E_e of 3.8, 3.9, and 4.4 MeV.

For further details of the general procedures such as, e.g., the calibration of the γ flux, the reader is referred to previous publications.[4,13,14]

III. RESULTS AND DISCUSSION

A. Spectra, yields

The sum of the pulse-height distributions observed at 96° [55-cm^3 Ge(Li)] and at 126° [45-cm^3

Ge(Li)] for a bombarding energy of $E_e = 4.8$ MeV is plotted in Fig. 1 down to energies of 2.8 MeV. Only full-energy peaks are labeled. With 0.64 cm of additional Pb in front of the 55-cm^3 detector, the counting efficiencies at the two scattering angles are almost identical, and the sums of the 96° and 126° counting rates amount to 1.8 times the isotropic rate, independent of whether the spin of the scattering level is 1 or 2. The peaks are thus representative of $g\Gamma_0^2/\Gamma$, with the lower energies favored for three reasons: the larger flux of incident γ rays, the λ^2 dependence of the yield, and the higher absolute detection efficiency.

Of the four levels above 2.8 MeV which are populated in the decay of ^{142}Pm [6] and have either spin 1 or spin 2, two, at 3.128 and 3.358 MeV, were not sufficiently excited by photons to show up in Fig. 1. Even more sensitive data, taken at bombarding energies below 3.425 MeV, failed to produce conclusive evidence for resonant scattering from these two levels.

Figure 2, again representing the sum of 96° and 126° pulse-height distributions, shows the region from $E_\gamma = 2.2$ MeV to $E_\gamma = 2.9$ MeV for a bombarding energy of 2.946 MeV. Comparison of the 2.846-MeV line in Figs. 1 and 2 illustrates the strong effect which the choice of the bombarding energy E_e has on the signal-to-background ratio in NRF experiments utilizing bremsstrahlung.

Of the known ^{142}Nd levels[6] with spin 1 or spin 2 in the region covered by Fig. 2, the 2.583-MeV 1^+ level[15] was the only one which was not clearly excited in the NRF experiments. Further experiments with $E_e < 2.846$ MeV provided, at best, marginal evidence for the excitation of this level.

In Table I are listed all the ^{142}Nd levels for which resonant scattering has been observed with bremsstrahlung of end-point energy ≤ 5 MeV. In addition, the spin-1 and spin-2 levels known from the study[6] of the decay of ^{142}Pm, but not observed, or only marginally observed in the NRF experiments, are also listed.

For the levels clearly excited by photons, the energies deduced from the NRF experiments are given in column 1 of Table 1, with the uncertainty in units of the last digit shown in parentheses. For the other levels, the energies were taken from Ref. 6. In column 2, the ratios of the 126° and 96° counting rates, observed with the 55- and 45-cm^3 detectors, are listed. 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 the data 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.

The spins derived from the NRF angular distribution data, while consistent with previously assigned[6,7,16] spins or spin choices, eliminated spin alternatives and tentative spin assignments for the 2.385-, 2.846-, 3.425-, and 4.145-MeV levels.

In column 4 of Table I are listed the Γ_0^2/Γ values extracted from the yields. In calculating these widths, the spin values listed in column 3 were used. For those levels for which a choice between spin 1 and spin 2 could not be made, spin 1 was assumed (arbitrarily) in calculating the Γ_0^2/Γ values.

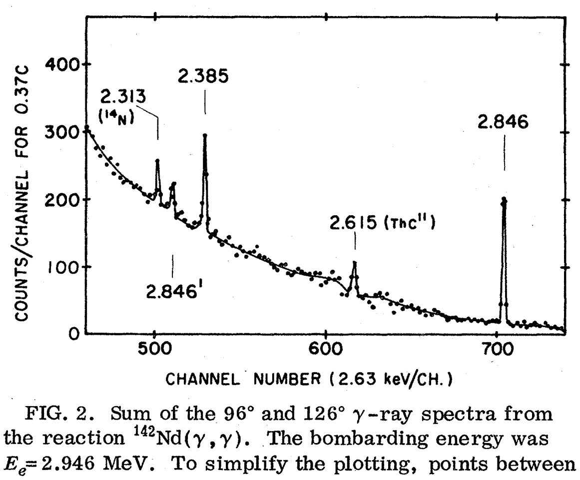

FIG. 2. Sum of the 96° and 126° γ-ray spectra from the reaction ^{142}Nd(γ,γ). The bombarding energy was $E_e = 2.946$ MeV. To simplify the plotting, points between peaks are 5.3 keV apart and represent the averages of adjacent channels.

B. Self-absorption, branching

The results of the self-absorption experiments are summarized in Table II.

For the 3.425-MeV transition, the natural width is no longer small compared with the Doppler width ($\Delta = 2.14$ eV), and the evaluation of the self-absorption data depends somewhat on the value of the ratio Γ_0/Γ. The width listed in Table II was calculated assuming $\Gamma_0/\Gamma = 1$. Since the 3.425-MeV ground-state transition is about as strong as any low-energy transition observed in the rare earths, branching to levels above the 1.576-MeV 2_1^+ state is expected to be very small because of the energy dependence of the transition rates. For the partial width Γ_1 of the transition $3.425 \rightarrow 1.576$, the inspection of the spectra yielded $\Gamma_1/\Gamma_0 = 0.02 \pm 0.08$. The ratio Γ_0/Γ is thus expected

TABLE II. Self absorption by 11.87 g/cm^2 of Nd metal (natural composition), i.e., by 1.35 ×10^{22} ^{142}Nd nuclei/cm^2.

E_{level}	$\frac{N(\text{res. absorber})}{N(\text{comparison abs.})}$	Γ_0 (meV) ^{a}
3.425	0.52 ± 0.02	355 ± 30
4.095	0.82 ± 0.09	150 ± 100
4.145	0.87 ± 0.13	110 ± 130

^{a}Assuming $\Gamma_0/\Gamma = 1$.

to fall into the interval $0.75 \leq \Gamma_0/\Gamma \leq 1$. With this range of Γ_0/Γ values, the self-absorption study leads to a partial width $\Gamma_0(3.425) = 370 \pm 45$ MeV. Comparison of this width with the Γ_0^2/Γ value obtained from the yielded data (Table I) indicates a nominal ground-state branching ratio $\Gamma_0/\Gamma = 0.89 \pm 0.16$.

For the 4.095- and 4.145-MeV transitions, the Γ_0/Γ dependence of the self-absorption result is considerably smaller than it is for the 3.425-MeV transition. On the other hand, branching to excited state is more probable for these two levels because the ground-state transitions are weaker. Based on the spectra, the ratio Γ_1/Γ_0 could be limited to $\Gamma_1/\Gamma_0 < 1$ for both levels. For a range $0.5 \leq \Gamma_0/\Gamma \leq 1$, the self-absorption data are consistent with $\Gamma_0 = 0.17 \pm 0.11$ eV for the 4.095-MeV level, and a range $\Gamma_0 = 0.11 \pm 0.15$ eV for the 4.145-MeV level.

For the three levels listed in Table II, the self-absorption and the yield data are consistent with $\Gamma_0/\Gamma = 1$.

C. Linear polarization, parities

The results of the linear polarization experiments are summarized in Table III. 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). Based on our experience, the ratio is expected to be approximately +4% for a 4-MeV $E1$ transition, and −5% for a 4-MeV $M1$ transition. The ratios increase with decreasing γ-ray energy.

TABLE III. ^{142}Nd: Results of the experiments using the Ge(Li) polarimeter.

E (MeV)	$100 \times \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$	Multipole character	J^{π}_{exc}
3.425	+1.9 ± 1.6	$E1$	1^-
4.095	−2.1 ± 4.2	$M1$ slightly favored	$1^{\pm}$
4.145	+8.9 ± 4.8	($E1$)	$1^{(-)}$

The negative parity deduced for the 3.425-MeV level from the polarization experiments is in accord with the (1^-) assignment made in Refs. 7 and 17.

For the 4.095-MeV level, the polarimeter result favors a 1^+ assignment. Positive parity for this spin-1 level is made more probable by the fact that the (p,p') experiments via isobaric analog resonances[6,7] did not excite this level.

Two levels at 4.117 and 4.141 MeV were most strongly excited in the (p,p') reaction[6,7] at the $\frac{3}{2}^-$ resonance and were identified as 2^- and 1^- states with the alternative of reversed spin assignments. Since the energies deduced from the NRF experiments were, in general, slightly higher than the energies assigned in the (p,p') studies, the 4.145-MeV level excited in the NRF experiments most probably corresponds to the 4.141-MeV level seen in the charged particle reaction. The unambiguous assignment (Table I) of spin 1 to the 4.145-MeV level then leaves 1^- as the only possible assignment for the 4.141-MeV level.

D. Remarks on individual levels

1. Level at 1.576 MeV

The NRF value for the reduced $E2$ transition probability for this 2_1^+ level, $B(E2\uparrow) = 0.225 \pm 0.020\ e^2 b^2$, is in good agreement with the accurate Coulomb excitation result[18] $B(E2\uparrow) = 0.268 \pm 0.003\ e^2 b^2$.

2. Level at 2.385 MeV

A study[6] of the decay of ^{142}Pm established the existence of branching from this level to the 2_1^+ state at 1.576 MeV. The reported ratio $\Gamma_1/\Gamma_0 = 0.18 \pm 0.04$ leads to a ground-state branching ratio $\Gamma_0/\Gamma = 0.85 \pm 0.03$. Combining this with the Γ_0^2/Γ value listed in Table I, a partial width

$$\Gamma_0(2.385) = (2.8 \pm 0.5)\text{meV}$$

is obtained. This in itself rules out a 2^- assignment, leaving 2^+ as the only assignment compatible with all the NRF information. Positive parity had also been favored by the ^{142}Pm decay data.[6] The electric quadrupole transition to the ground state has a strength of 1 single particle unit (spu). The partial width Γ_1 of the 0.809-MeV cascade transition $2_2^+ \to 2_1^+$ is $\Gamma_1 = 0.5$ MeV, corresponding to ≈ 40 $E2$ spu's. This indicates that an $M1$ admixture might account for a good fraction of Γ_1.

3. Level at 2.583 MeV

According to Ref. 6, the ground-state branching ratio for this level is $\Gamma_0/\Gamma = 0.69 \pm 0.04$. The partial width Γ_0 is then $\Gamma_0(2.583) = (0.9 \pm 1.1)$ meV. The level has been characterized[15] as a 1^+ state.

The ground-state transition is a weak $M1$ with $\Gamma_0 < 10^{-2}$ spu.

4. Level at 2.846 MeV

Neither the NRF spectra nor the studies[6] of the decay scheme of ^{142}Pm revealed any branching from this 2^+ level to excited states of ^{142}Nd. The situation may be summarized by $\Gamma_0/\Gamma = 1.00 \pm 0.16$. With this, the result of the yield measurements (Table I) leads to

$$\Gamma_0(2.846) = (11.5 \pm 2.1)\ \text{meV},$$

It might be mentioned that this considerable width is not compatible with a 2^- assignment, since it corresponds to $\approx 150 M2$ spu. The $E2$ strength is slightly enhanced (1.7 spu).

5. Level at 3.046 MeV

The most probable spin-parity assignment for this level is 2^+. In the study[6] of the decay of ^{142}Pm, no branching to excited states of ^{142}Nd was observed, i.e., $\Gamma_0/\Gamma = 1$. However, the sensitivity was such that Γ_0/Γ values as low as 0.5 could not be excluded.

The observed width, $\Gamma_0^2/\Gamma = (1.4 \pm 0.6)$ meV, corresponds to 0.15 ± 0.06 $E2$ spu.

6. Level at 3.128 MeV

This level is populated in the decay of ^{142}Pm and has been characterized[6] as $1^{(+)}$ or $2^{(+)}$. The relatively small ground-state branching ratio $\Gamma_0/\Gamma = 0.33 \pm 0.09$[6] renders observation of this level via NRF utilizing bremsstrahlung more difficult. No clear evidence for excitation by photons was obtained, and the result of the NRF study may be expressed as

$$g\Gamma_0(3.128) = (5.5 \pm 8.5)\ \text{meV},$$

where $g = 2J_{\text{exc}} + 1$ for ^{142}Nd.

7. Level at 3.358 MeV

This is another level, populated[6] in the decay of ^{142}Pm, which was not observed in the NRF experiments. According to Ref. 6, the possible spins are 1 and 2, and the ratio Γ_0/Γ is unity or at least >0.8. With $\Gamma_0/\Gamma = 1$, the NRF experiment leads to a width

$$\Gamma_0(3.358) = (0.3 \pm 3.0)\ \text{meV},$$

8. Level at 3.425 MeV

This level represents the strongest (γ, γ) excitation in ^{142}Nd below 5 MeV. The width $\Gamma_0 = 370 \pm 45$ MeV derived from the self-absorption data corresponds to a reduced $E1$ transition probability $B(E1, 0 \to 1^-) = (5.0 \pm 0.6) \times 10^{-3}$ spu. This is comparable to, though slightly higher than, the $B(E1)$'s for the corresponding 1^- levels in the other $N = 82$ nuclei ^{138}Ba (4.027 MeV),[19] ^{140}Ce(3.644 MeV),[9] and ^{144}Sm(3.225 MeV).[10] All these levels are presumably the lowest 1^- states in their respective nuclei and occur at excitation energies which are close to the sums of the excitation energies of the 2_1^+ and 3_1^- levels. This suggests that these levels are the 1^- members of the negative-parity quintuplet arising from the coupling of the collective quadrupole and octupole vibrational states.[6,20] In all four even-even $N = 82$ nuclei studied so far, the ground-state transitions from these 1^- excitations are the strongest $E1$ transitions below 5 MeV. Furthermore, it appears from measurements in ^{136}Ba ($N = 80$),[21] ^{144}Nd ($N = 84$),[4] and ^{148}Sm ($N = 86$)[3,10] that the $B(E1)$'s for the presumed $[2^+ \otimes 3^-]\ 1^-$ levels peak at $N = 82$, and that comparable $B(E1)$'s are not found again until one reaches the deformed region ($N > 88$).

9. Level at 4.095 MeV

In Sec. III C, a 1^+ assignment was proposed for this level. A two-quasiparticle 1^+ state involving the spin-orbit pair $d_{3/2} - d_{5/2}$ is expected[22] in ^{142}Nd at an excitation energy of ≈ 4 MeV. States involving the $p_{1/2} - p_{3/2}$ spin-orbit pair have been excited by photons in ^{88}Sr at 3.487 MeV[23] and in ^{206}Pb at 1.704 MeV.[14] In both cases, good agreement between the experimental and the theoretical $B(M1)$'s was achieved after the mixing with the giant magnetic dipole state and ground-state correlations had been taken into account.[24,25]

In a recent NRF study of ^{144}Sm,[10] a fairly large yield of 3.966-MeV γ rays was observed. It was attributed to a $1^{(+)}$level. Since the excitation energies of the two-quasiparticle 1^+ states in the $N = 82$ even-even nuclei are expected[22] to decrease with increasing atomic number Z, the 3.966-MeV level in ^{144}Sm might be the equivalent of the 4.095-MeV level in ^{142}Nd.

It should be mentioned at this point that NRF experiments involving natural Nd and enriched ^{144}Nd scatterers[21] showed that a spin-1 level at 4.095 ± 0.003 MeV excitation energy exists in ^{144}Nd. The width of this level is comparable to the width of the 4.095-MeV level in ^{142}Nd.

10. Level at 4.145 MeV

This level is presumably[7] the 1^- member of the $p_{3/2} \otimes (d_{3/2})^{-1}$ neutron particle-hole multiplet (see also Sec. III C). Considering the large uncertainty of the self-absorption result, Γ_0/Γ is assumed to be unity, and thus (Table I) $\Gamma_0 = 0.085$ eV. This width corresponds to a reduced $E1$ transition probability $B(E1,\ 0\to 1^-) = (6.5 \pm 1.5)\times 10^{-4}$ spu. Thus the strength of the 4.145-MeV transition amounts to only $\frac{1}{7}$ of the strength of the 3.425-MeV transition.

11. Level at 4.255 MeV

No level at or near this energy was reported from the (p,p') IAR experiments.[6,7] The assignment of the 4.225-MeV level to ^{142}Nd is based on the high enrichment of the scattering material used in the NRF experiments and on the absence of a strong 4.225-MeV γ line in spectra observed at $E_e = 4.30$ MeV with a natural Nd scatterer.

12. Level at 4.625 MeV

This spin-(1) level might be identical with the 4.618-MeV level reported in Refs. 6 and 7.

13. Level at 4.901 MeV

A (1^-) level at 4.896 MeV, reported in Ref. 7, is likely to be identical with the 4.901-MeV level observed in the NRF experiments. A spin assignment based on the NRF data could not be made because only the 55-cm^3 Ge(Li) detector at a scattering angle of 96° was operational at the time of the $E_e = 5$ MeV bombardment.

ACKNOWLEDGMENTS

The author gratefully acknowledges helpful discussions with Dr. V. K. Rasmussen. He is indebted to the Research Division of ERDA for arranging the loan of the ^{142}Nd sample. This research was supported in part by the National Science Foundation.

[1]F. R. Metzger and V. K. Rasmussen, Phys. Rev. C 8, 1099 (1973).
[2]F. R. Metzger and V. K. Rasmussen, Bull. Am. Phys. Soc. 18, 1386 (1973).
[3]F. R. Metzger, Phys. Rev. 137, B1415 (1965).
[4]F. R. Metzger, Phys. Rev. 187, 1700 (1969).
[5]A. Bohr and B. R. Mottelson, Nucl. Phys. 4, 529 (1957).
[6]S. Raman, J. L. Foster, Jr., O. Dietzsch, D. Spalding, L. Bimbot, and B. H. Wildenthal, Nucl. Phys. A201, 21 (1973).
[7]L. Bimbot, L. Lessard, S. Santhanam, R. Martin, O. Dietzsch, D. Spalding, K. Schechet, and J. L. Foster, Jr., Phys. Rev. C 9, 741 (1974).
[8]On loan from the Stable Isotope Cross Section Research Pool of the Division of Research, U. S. Energy Research and Development Administration.
[9]F. R. Metzger, in *Proceedings of the International Conference in Nuclear Structure and Spectroscopy, Amsterdam*, 1974, edited by H. P. Blok and A. E. L. Dieperink (Scholar's Press, Amsterdam, 1974), Vol. 1, p. 209.
[10]F. R. Metzger, Phys. Rev. C 17, 939 (1978).
[11]F. R. Metzger, Phys. Rev. C 14, 543 (1976).
[12]A. E. Litherland, G. T. Ewan, and S. T. Lam, Can. J. Phys. 48, 2320 (1970).
[13]F. R. Metzger, Phys. Rev. 187, 1680 (1969).
[14]F. R. Metzger, Ann. Phys. (N.Y.) 66, 697 (1971).
[15]J. Tenenbaum, R. Moreh, and A. Nof, Nucl. Phys. A218, 95 (1974).
[16]J. F. Lemming and S. Raman, Nucl. Data 10, 309 (1973).
[17]K. Heyde, M. Waroquier, and H. Vincx, Nucl. Phys. A234, 216 (1974).
[18]G. Kindleben and Th. W. Elze, Annual Report, Institut für Kernphysik, Frankfurt/Main, 1975 (unpublished), p. 12.
[19]C. P. Swann, Phys. Rev. C 15, 1967 (1977).
[20]P. Vogel and L. Kocbach, Nucl. Phys. A176, 33 (1971).
[21]F. R. Metzger (unpublished).
[22]R. J. Lombard, Phys. Rev. Lett. 21, 102 (1968).
[23]F. R. Metzger, Nucl. Phys. A173, 141 (1971).
[24]K. Harada and S. Pittel, Phys. Lett. 32B, 542 (1970).
[25]F. E. Cecil, T. T. S. Kuo, and S. F. Tsai, Phys. Lett. 45B, 217 (1973).