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Low-lying levels in ^{76}Br

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Gamma rays from the reaction ^{76}Se $(p,n\gamma)^{76}$Br were observed at proton energies between 5.80 and 6.50 MeV. A total of 35 γ rays were assigned to transitions in ^{76}Br. A level scheme involving 15 levels up to an excitation energy of 616.3 keV was deduced from threshold measurements, energy sums, and γ-γ coincidence studies. These results have resolved disagreements between two previous experiments involving the β-decay of ^{76}Kr. Previously unreported levels have been assigned at 495.4, 505.0, 527.5, and 548.0 keV.

[NUCLEAR REACTIONS ^{76}Se$(p,n\gamma)$, $E=5.80-6.50$ MeV; measured E_γ, I_γ, $\gamma\gamma$ coin: ^{76}Br deduced levels. Enriched target, Ge(Li) detectors.]

A recent compilation[1] of nuclear structure data for ^{76}Br includes results[2,3] from the electron capture decay of ^{76}Kr, and preliminary results[4] from our study of the ^{76}Se$(p,n\gamma)^{76}$Br reaction. We describe here more complete results from the latter reaction. Several disagreements in the level assignments from the ^{76}Kr decay studies are resolved in the present work, and a consistent level scheme is given for the low-spin levels of ^{76}Br. The γ rays recently reported by Behar *et al.*[5] from the ^{75}As$(\alpha,3n\gamma)^{76}$Br reaction apparently involve at most one level deduced from ^{76}Kr(ϵ) or ^{76}Se$(p,n\gamma)$, and therefore must be assigned as originating from levels having higher spins than those given in Ref. 5.

Our experimental data were obtained using the FN tandem at the U. S. Army Ballistic Laboratories. Targets were prepared by evaporating 86.1% enriched ^{76}Se onto thin (30 μg/cm^2) carbon backings. Based on the geometry of the evaporation process, the thickness of the selenium foils was estimated to be approximately 1 mg/cm^2.

γ rays were detected by two lead shielded 30 cm^3 Ge(Li) detectors placed at ±110°. Signals were processed by conventional modular electronics and routed to a Systems 86 computer. A time resolution of 20 ns was obtained for γ-γ coincidence studies. The pulse heights for each coincidence event were recorded pairwise in the computer memory and assigned to locations in a 319 by 319 matrix. Data were transferred to magnetic disk and played back through digital restriction windows set on one detector allowing a sorting of the matrix into spectra of coincidence γ rays seen by the other detector.

Singles measurements with the Ge(Li) detector spectra were taken in steps of 10–25 keV from below threshold ($Q=-5.739\pm0.015$ MeV[6]) to 6.45 MeV ($E_x=627$ keV). Beam currents were maintained at approximately 50 nA in order to prevent target deterioration and to keep dead times below 10%. Counting times were in the range of 25–35 min. Coincidence measurements were performed during one 11 h run at an energy of 6.50 MeV. Further details of the experimental techniques have been published.[4,6-8]

Table I lists the γ rays attributed to transitions in ^{76}Br along with their assignments and relative intensities at 110°.

The proposed level scheme for ^{76}Br as deduced from the present work is shown in Fig. 1. In this scheme we have fitted 35 γ rays involving 15 levels. Paradellis *et al.* (P) have fitted 27 γ rays and Lode *et al.* (L) 23 γ rays in this same range of excitation energy. In all cases we agree with level assignments common to both the P and L decay schemes.[9] Disagreements between the schemes of P and L have been resolved in the present work. As expected these disagreements appear most frequently for levels and cascade γ rays which P or L determined on the basis of energy sums alone.

Behar *et al.* report eight γ rays from ^{76}Br, all of which they assign to a single quasirotational band. Of their γ rays, only the 141.8 keV transition was observed by us, and weakly, by L. Nei-

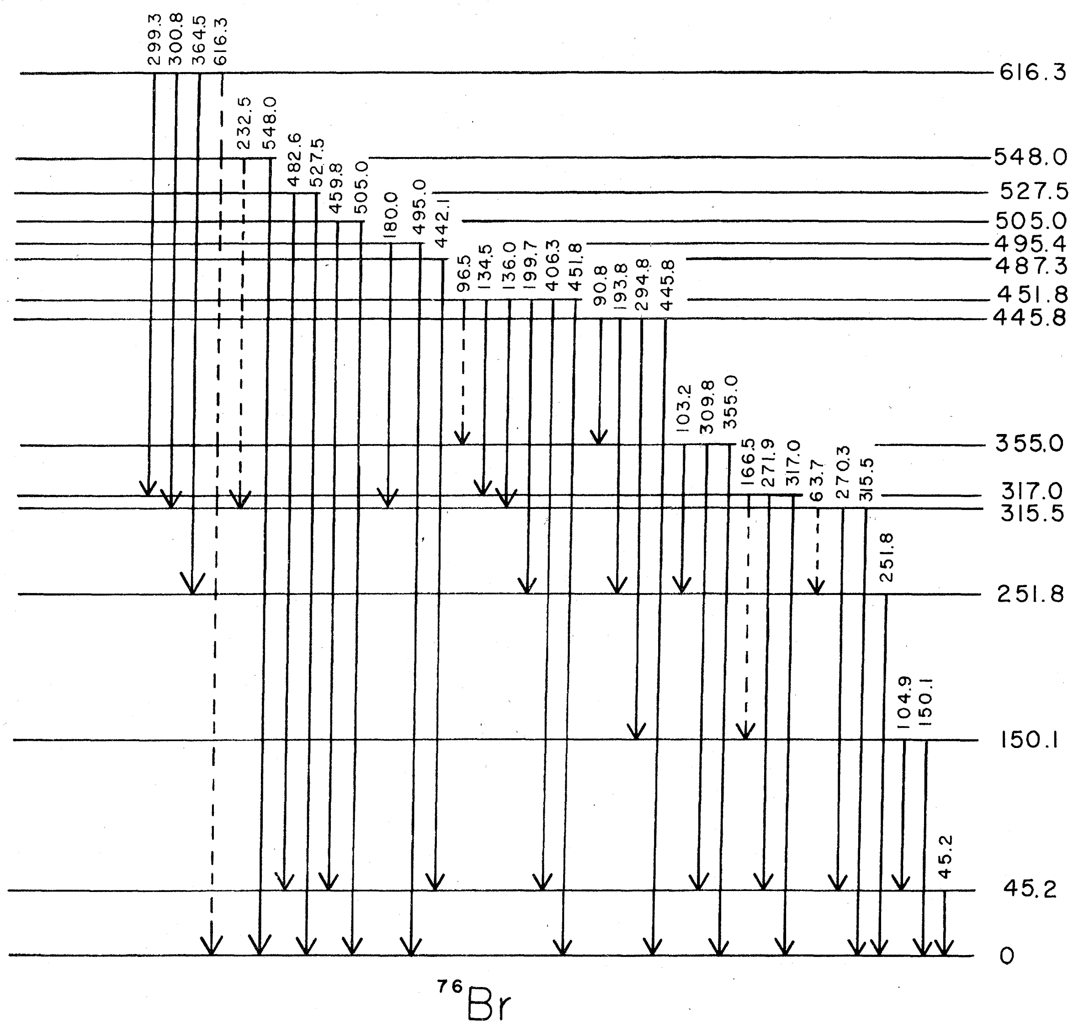

FIG. 1. Level scheme for ^{76}Br as deduced from the present experiment.

ther we nor L can fit the 141.8 keV γ ray into the level scheme, though Behar *et al.* assign it as a ground-state transition. This discrepancy can be resolved by assuming that the cascade from the $(\alpha, 3n\gamma)$ reaction terminates at an excited level rather than the ground level.

In the following discussion we will primarily comment on levels in the present scheme which differ appreciably from those proposed by P and L. In most cases we have assigned levels based on threshold behavior, energy summing, and γ-γ coincidences.

45.2 and 251.8 keV levels. We are in complete agreement with the results of P and L in these assignments. Both the 251.8 and 45.2 keV lines show excellent threshold behavior for levels at these energies.

150.1 keV level. Both the 150.1 and 104.9 keV lines associated with the decay of this level are relatively weak and display only moderately good threshold behavior. These regions of the spectra contain several contaminants which make it difficult to obtain consistent yields. Good coincidences between the 104.9 and 45.2 keV lines help to confirm the existence of this level. These observations are in agreement with the work of L and P.

260.0 keV level. There is no evidence in our data indicating the presence of a level at this energy, as suggested by P. We do observe a 215 keV line, but it does not show proper threshold behavior to be a 260 → 45 keV transition as assigned by P, and the level cannot be confirmed by our coincidence studies.

280.0 keV level. On the basis of summing only,

TABLE I. γ ray energies, relative intensities, and assignments.

$E_\gamma \pm 0.4$ (keV)	I_{rel} ($\theta = 110°$) $E_p = 6.45$ MeV	Assignment
35.6	<2	
40.0	<1	
45.2	190	g.s.
63.7	3	(315→252)
80.0	1.1	
90.8	9.4	446→355
96.5	<1	(452→355)
103.2	21	355→252
104.9	1.7	150→45
134.5	2.6	452→317
136.0	1.1	452→315
138.9	5.8	
141.7	15	
150.1	24	g.s.
166.5	79	(317→150)
180.0	2.1	495→315
193.8	13	446→252
199.7	50	452→252
214.7	5.2	
232.5	4.3	(548→315)
251.8	100	g.s.
262.5	21	
270.3	87	315→45
271.9	19	317→45
294.8	50	446→150
299.3	4.0	616→317
300.8	2.0	616→315
309.8	26	355→45
315.5	81	g.s.
317.0	21	g.s.
355.0	42	g.s.
364.5	9.8	616→252
401.4	2.9	
406.3	17	452→45
442.1	9.3	
445.8	9.6	g.s.
451.8	15	g.s.
459.8	6.1	495→45
482.6	2.2	528→45
495.4	9.1	g.s.
505.0	16	g.s.
527.5	7.1	g.s.
548.0	7.4	g.s.
616.1	<2	(g.s.)

P fitted this level into their decay scheme. It is presumed to decay via a 235 keV γ ray to the 45 keV state. Neither the present work nor the work of L shows this γ ray. We do observe a 36 keV transition, but its threshold behavior does not indicate it is a 315→280 keV cascade as suggested by P. A weak 215 keV transition shows fairly good threshold behavior to support a 495 to 280 keV cascade but in light of this weak evidence we cannot confirm the existence of this level.

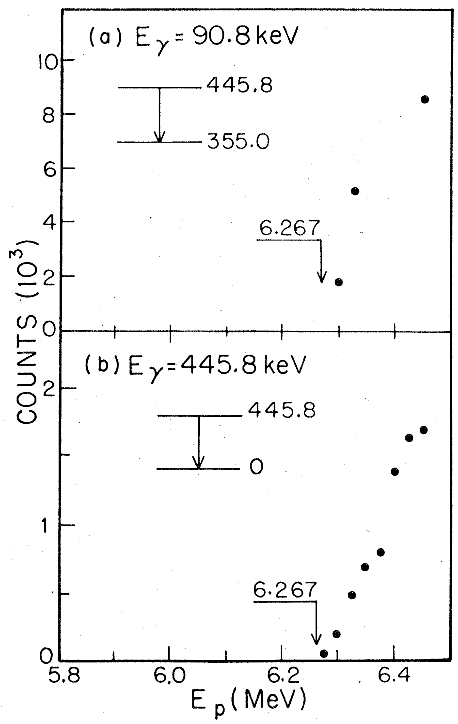

FIG. 2. γ ray yield curves for 90.8 and 445.8 keV transitions in ^{76}Br. Arrows with numbers indicate expected threshold energy.

315.5 and 317.0 keV levels. The yield curves for the unresolved 315.5+317.0 and 270.3+271.9 keV doublets indicate the presence of a level at approximately 316 keV. Both sets of doublets were resolved in the coincidence studies which indicated the presence of a 317.0 keV ground-state transition not observed by P and L. Also we and P assign a 64 keV γ ray as a 315→252 keV cascade while L assign this line to a 932→868 keV cascade. Since we are far below the excitation energy for a 932 keV level we must rule out this assignment of L.

355.0 keV level. We are in complete agreement with P and L in the assignment of this level and its decay modes. We observe a 40.0 keV line but are unable to directly confirm a 355→315 keV cascade since the large background in the singles spectra in this region made it difficult to obtain a consistent yield curve and the coincidence studies do not extend down to 40 keV.

431.9 keV level. There is no evidence in our data for a 431.9 keV level as tentatively suggested by L. They report γ rays of energies 76.3, 179.9, and 431.9 keV. Of these we observe only a 180.0 keV line, which we assign as a cascade from a new level at 495.4 keV. P report a line at 431.6 keV which they assign as a cascade from a level at 1048 keV.

445.8 keV level. Our data [Figs. 2(a) and 2(b)] clearly establish the existence of this level in support of P and their decay scheme. L see 90.9 and 446.5 keV lines but assign them to transitions from other levels higher than our maximum excitation energy. Our coincidence data (Fig. 3) also support the existence of this level.

451.8 keV level. Threshold behavior of the 451.8, 406.3, and 134.5 keV lines all support a level at 451.8 keV. The evidence for cascades of 96.5 and 199.7 keV is less definite. The former is very weak and the latter is contaminated by the presence of the strong 199 keV line from ^{77}Br. The coincidence data, however, do confirm the existence of the 199.7 keV cascade. These results agree with the results of L and P. The 96.5 keV line does not appear in coincidence and is weak in singles.

487 keV level. We are in agreement with L's assignment of a level at this energy, but for different reasons. L propose the 487 keV level on the basis of a 171 + 317 keV sum relation and a 35 + 452 keV coincidence. However, we do observe a 45 + 442 keV coincidence, and the threshold behavior of the 442 keV γ ray supports the existence of this level.

495 keV level. The 495.4 keV line is weak but shows good threshold behavior for a level at this energy. The threshold behavior for the weak 180.0 keV line is less convincing as a transition from this level but did show a moderately strong coincidence with the 315.5 and 272 keV lines. Neither P nor L report a 495 keV transition but L see a 180 keV line which they assign to a 432 → 252 keV transition. As we have previously mentioned we find no evidence to support the existence of a 432 keV level.

505.0 keV level. Two transitions, the ground state and 505.0 → 45.2 keV, were observed, and

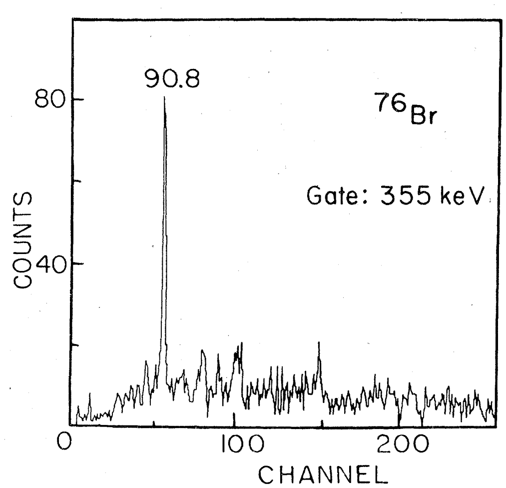

FIG. 3. Coincidence spectrum at E_p = 6.50 MeV.

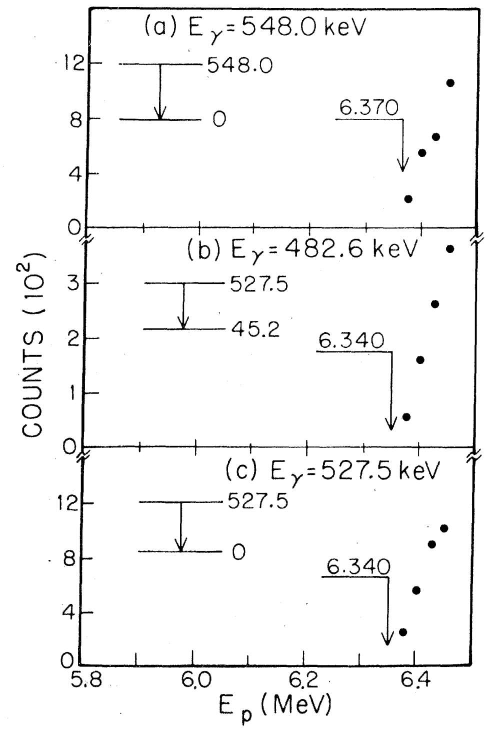

FIG. 4. γ ray yield curves for 548.0, 482.6, and 527.5 keV transitions in ^{76}Br. Arrows with numbers indicate expected threshold energy.

displayed threshold behavior supporting a level at this energy. Neither P nor L report a 505 keV transition but P report a 459 keV line which they assign as 815 → 355 keV transition. Since we are below the threshold for a 815 keV level we cannot support their interpretation of this γ ray.

527.5 and 548.0 keV levels. Figure 4 displays the yield curves for transitions from two new levels at 527.5 and 548.0 keV. Of these three lines only the 548 keV line was seen by P and L. No assignment was made by them. We also see a line at 232.5 keV which could be a 548 → 315.5 keV transition. However, the threshold and coincidence results were not conclusive in this assignment, and we make only a tentative assignment. The 232.5 keV line was also seen by P and L but they made no assignment for it.

616 keV level. At the highest bombarding energy used in obtaining the yield curves (6.45 MeV) we are about 25 keV above threshold for a level at 616 keV. At this energy we observe a very weak peak with an energy close to 616 keV. However the coincidence run at 6.50 MeV shows several strong peaks indicating 616 → 252, 616 → 317, and 616 → 315 keV cascades.

In summary, we concur with P and L on their assignments of levels at 45.2, 150.1, 251.8, 315.5, 317.0, 355.0, and 451.8 keV. We have no evidence to support P on their assignment of levels at 260.0 and 280.0 keV, but do agree with them on the existence of a 445.8 keV level. We find no evidence to support the existence of a level at 431.9 keV as suggested by L but concur in their assignment of a level at 487 keV. Also, our data are not inconsistent with a level at 616 keV, as assigned by both L and P. New levels which have been assigned as a result of the present work are at 495.4, 505.0, 527.5, and 548.0 keV.

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[9]We use the convention of letter designations for these often repeated references by assigning Paradellis *et al.* (Ref. 2) the letter P and Lode *et al.* (Ref. 3) the letter L.