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Spectroscopy of gamma rays from ^{78}As decay

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Gamma rays accompanying the β^- decay of ^{78}As to ^{78}Se have been studied using a high purity source and large volume germanium detectors. Seventeen new γ rays have been observed and eight previously reported gamma rays have been excluded. From singles and γ-γ coincidence data new levels are proposed at 1758.9, 2334.9, 2647.7, and 3372.7 keV, whereas the 1693-, 1721-, 2452-, 2798-, 3192-, 3528-, and 3984-keV levels proposed in earlier studies have been withdrawn from the ^{78}As decay scheme. Deduced $B(E2)$ ratios have been compared with theoretical calculations based on an anharmonic oscillator model.

[RADIOACTIVITY ^{78}As [from ^{78}Se (n,p)]; measured E_γ, I_γ, γ-γ coin; deduced: ^{78}Se levels, $B(E2)$ ratios. Enriched ^{78}Se target, Ge and Ge(Li) detectors.]

I. INTRODUCTION

The importance of the level structure of ^{78}Se lies in the systematic study of the behavior of nuclear shapes in the region limited by neutron number in the range 40 to 50 and proton number 28 to 40. The even-even stable selenium nuclei have long been considered as candidates for description in terms of a collective oscillator with small anharmonic effects to explain the observed spectral features at low excitation energies. Recent Coulomb excitation experiments,[1] however, have shown that these nuclei also exhibit static deformations. Study of ^{78}As decay is one of about ten different methods[2] by which the low spin ($J \leq 4$) level structure of the ^{78}Se nucleus has been investigated in the past. Previous studies[3–6] of the decay of ^{78}As generally employed sources of relatively low purity made from irradiation of natural Br and Se targets with fast neutrons. Significant amounts of ^{76}As and ^{81}Se were produced in these cases. Fettweiss and Marmol[7] used thermal neutron fission of ^{235}U and chemically separated ^{78}Ge activity. They studied the decay chain ^{78}Ge $\rightarrow$ ^{78}As $\rightarrow$ ^{78}Se. Gamma rays from ^{78}Ge and ^{77}Ge contributed to the complexity of the observed spectra. All the γ-ray studies[3–7] used relatively small Ge(Li) detectors for singles measurements and Ge(Li)-NaI(TI) systems for coincidence experiments.

The results of the above-mentioned studies showed a number of discrepancies in γ-ray energies and transition placements. In several cases, the energies of γ rays differed by 1 keV or more. Two significant improvements in the present experimental conditions led us to expect that some of the discrepancies could be resolved through another γ-ray spectroscopic study of ^{78}As decay. An enriched ^{78}Se target (97%) was irradiated with fast neutrons to obtain a relatively pure source of ^{78}As and the coincidence spectrometer used for the measurements consisted of two 10% high resolution detectors—one Ge(Li) and the other intrinsic Ge.

II. EXPERIMENTAL PROCEDURES

The ^{78}As source material was prepared by irradiating 150 mg of 97.27% enriched ^{78}Se powder with 14-MeV neutrons produced by a neutron generator. The relevant reaction was ^{78}Se$(n,p)^{78}$As. The only significant radioactive impurity was ^{75}Ge produced through the ^{78}Se$(n,\alpha)^{75}$Ge reaction. The ^{75}Ge activity contributed only two γ rays with energies of 198.6 and 264.6 keV. A trace amount of ^{77}As was also present which gave rise to a very weak peak at 239.0 keV.

The singles γ-ray spectrum was obtained with an intrinsic Ge detector which has an energy resolution of 1.7 keV at 1330 keV and an efficiency of about 10%. The electronics system, conventional in design, employed a main amplifier, a linear gate and stretcher, a 4096-channel analog-to-digital converter (ADC), and a PDP 11/10 computer (Digital Equipment Corp). The detector was located inside a lead shield with 6 cm thick walls. The source-to-detector distance was 5 mm. At this distance some γ-ray summing occurred, but the sum lines were very weak in the observed spectra. The only contribution to the observed spectra from the room background was due to a line at 1460 keV from ^{40}K. The energy calibration was carried out by the usual technique of obtaining a spectrum by counting the standard sources and the ^{78}As sample simultaneously. The standard sources used were ^{56}Co, ^{60}Co, ^{208}Tl, ^{212}Pb, ^{228}Ac, and ^{40}K.

The γ-ray peaks in both spectra were analyzed using a computer program which gave the channel number of the centroid of each line, the area under each line after subtracting the background and the energy. The relative intensities of the γ rays were determined through the use of a predetermined efficiency curve for the detector.

The γ-γ coincidence spectrometer consisted of the above counter and a Ge(Li) detector with a resolution of 2.3 keV and 10% efficiency. The time resolution of the coincidence system was about 10 ns. Coincidence data were stored on a magnetic tape as pairs of addresses, one from each ADC. The sorting of these two-parameter data was carried out in an off-line mode. A total of 68 gates were chosen in the analysis of the γ-γ coincidence data.

III. EXPERIMENTAL RESULTS

The γ-ray spectrum obtained with the intrinsic Ge detector is shown in Figs. 1(a)—(c). The results of the analysis of this spectrum are given in Table I together with the results from earlier studies.[3–7] The overall limit of detection for γ rays in the present experiment was about 0.1% of the intensity of the strongest line, at 613.8 keV. Absolute total transition intensities can be obtained by using a multiplication factor of 0.52. The correction due to internal conversion is negligible. The revisions to the level scheme given in Fig. 2 are based primarily on the present γ-γ coincidence measurements. The conclusions from the coincidence data are shown in Fig. 2 by dots at the beginning and/or at the end of a transition, indicating that the γ ray was seen in coincidence with a preceding and/or a following transition, respectively. The level energies given in Fig. 2 have been calculated from a least-square fitting of transition energies given in Table I. The $\log ft$ values have been determined by using $Q(\beta^-)=4290$ keV and a half-life of 90.7 min.[2] The feeding to the ground state of ^{78}Se has been deduced from the measurement of the absolute intensity of the 613.8-keV γ ray by Fettweis and Marmol.[7]

IV. DISCUSSION OF RESULTS

The γ-ray spectrum given in Fig. 1 reveals 17 new transitions, whereas eight previously reported γ rays were not observed. The precision on γ-ray energies is generally better than that achieved in earlier studies. The present singles and coincidence data lead to a substantial revision of the decay schemes of ^{78}As proposed earlier.[3–5] New levels are established at 1758.9, 2334.9, 2647.7, and 3372.7 keV, whereas levels[3–7] at 1693, 1721, 2452, 2798, 3192, 3528, and 3984 keV proposed earlier have been withdrawn. A level-by-level discussion follows which outlines the evidence for the proposed revisions. The results from radiative neutron-capture experiments,[8,9] where available, generally agree with the conclusions drawn from the present work. Some of the discrepancies between the present data and (n,γ) data[8,9] are pointed out in the following discussion.

Level at 1758.9 keV. The observation of a 1145.1-keV γ ray in coincidence with the 613.8-keV γ ray leads us to establish a new level at 1758.9 keV. A newly reported 449.8-keV γ ray most likely couples this level to the 1308.6-keV level.

This placement of the 1145.1-keV transition excludes the 2452-keV (Refs. 3 and 5) and 3984-keV (Ref. 4) levels proposed earlier. The 1301- and 1476-keV γ rays connected with the 3984-keV level were not observed in the present work. The 2452-keV level had been defined by the 1145-keV γ ray only.

Level at 1853.9 keV. The γ ray doublet at 354 keV has been properly resolved in the present study. Precise energies for the two components, 351.1 and 354.3 keV, and γ-γ coincidence results clearly establish that the two γ rays deexcite levels at 1853.9 and 2682.0 keV. An incorrect conclusion was reached

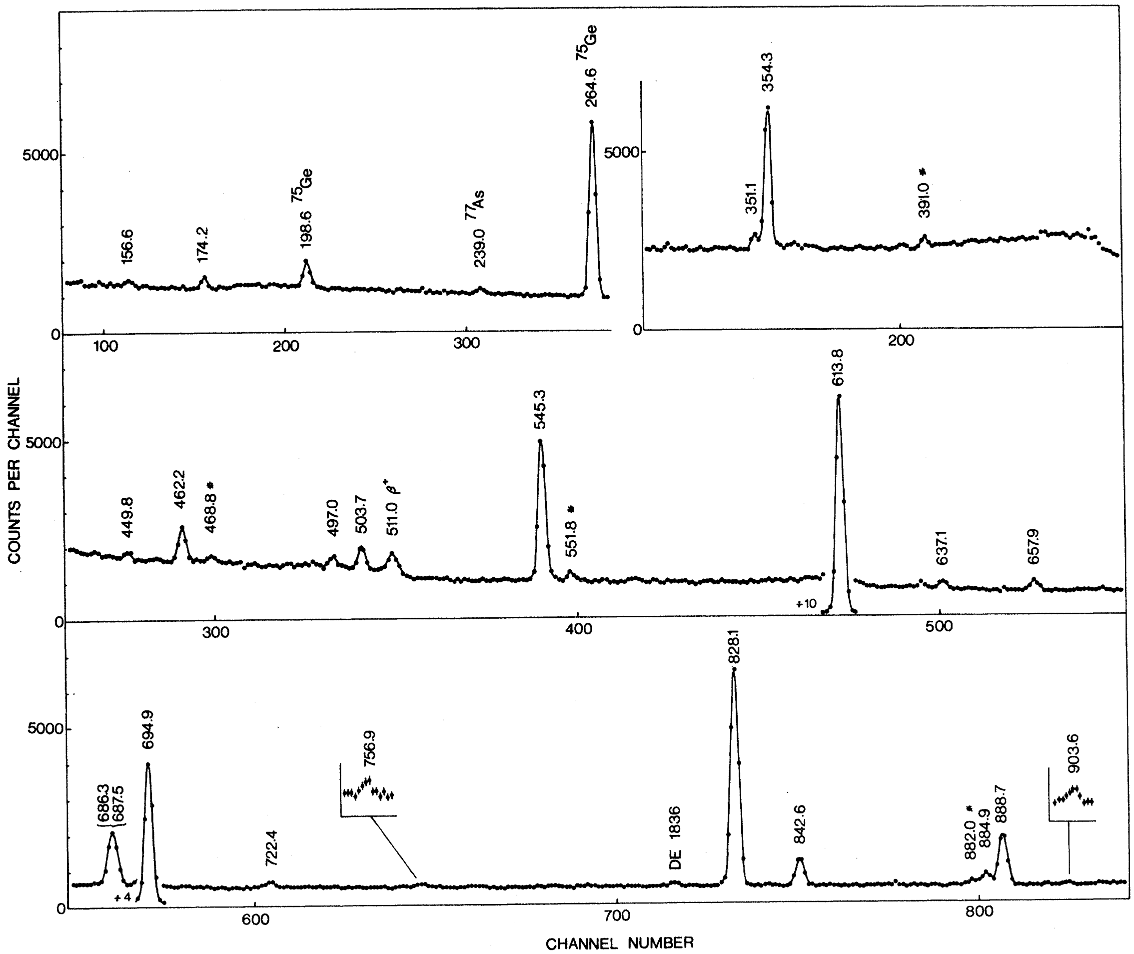

FIG. 1. Singles γ ray spectrum from ^{78}As source produced by irradiation of enriched ^{78}Se with 14-MeV neutrons. Abbreviations: SE—single escape peak; DE—double escape peak; Σ— summation peak; * — unplaced γ rays.

in a (n,γ) experiment,[8] which placed the stronger component with the 1853.9-keV level.

Level at 1995.9 keV. From singles and coincidence data two new transitions have been added to this level—a newly observed 497.0-keV γ ray and the 687.5-keV component of the previously unresolved doublet at 686 keV.

Level at 2327.4 keV. Two additional transitions of 1018.7 and 2327.1 keV deexcite this level; the former is a new γ ray observed in the present work. There is no evidence for placing a part of the 828.1-keV γ ray with this level as was suggested in (n,γ) work.[8]

Level at 2334.9 keV. The coincidence of the 1721.0- and 694.9-keV γ rays establishes this new level. Previous assignments of the 1721.0-keV γ ray with a 1721-keV level[4] or a 3711-keV level[5] were found to be incorrect. The 1721-keV level has been withdrawn whereas the 3711-keV level is now established by a 3097.5-keV transition only.

Level at 2507.7 keV. A 786.2-keV γ ray with an intensity of 0.22 reported only by Morcos *et al.*[4] has been excluded since it was not observed in the present spectrum.

Level at 2537.4 keV. Morcos *et al.*[4] suggested that the two components of the doublet at 1923 keV deexicted levels at 3227 and 3232 keV. Our γ-γ data reveal, however, that the 1921.0- and 1923.5-keV γ rays should be placed with the 3229.7- and 2537.4-keV levels, respectively. This conclusion also suggests that the 3232-keV level shown by Morcos *et al.*[4] needs to be withdrawn.

A γ ray of 848.7 keV with an intensity of 0.32 reported only by Morcos *et al.*[4] has been excluded

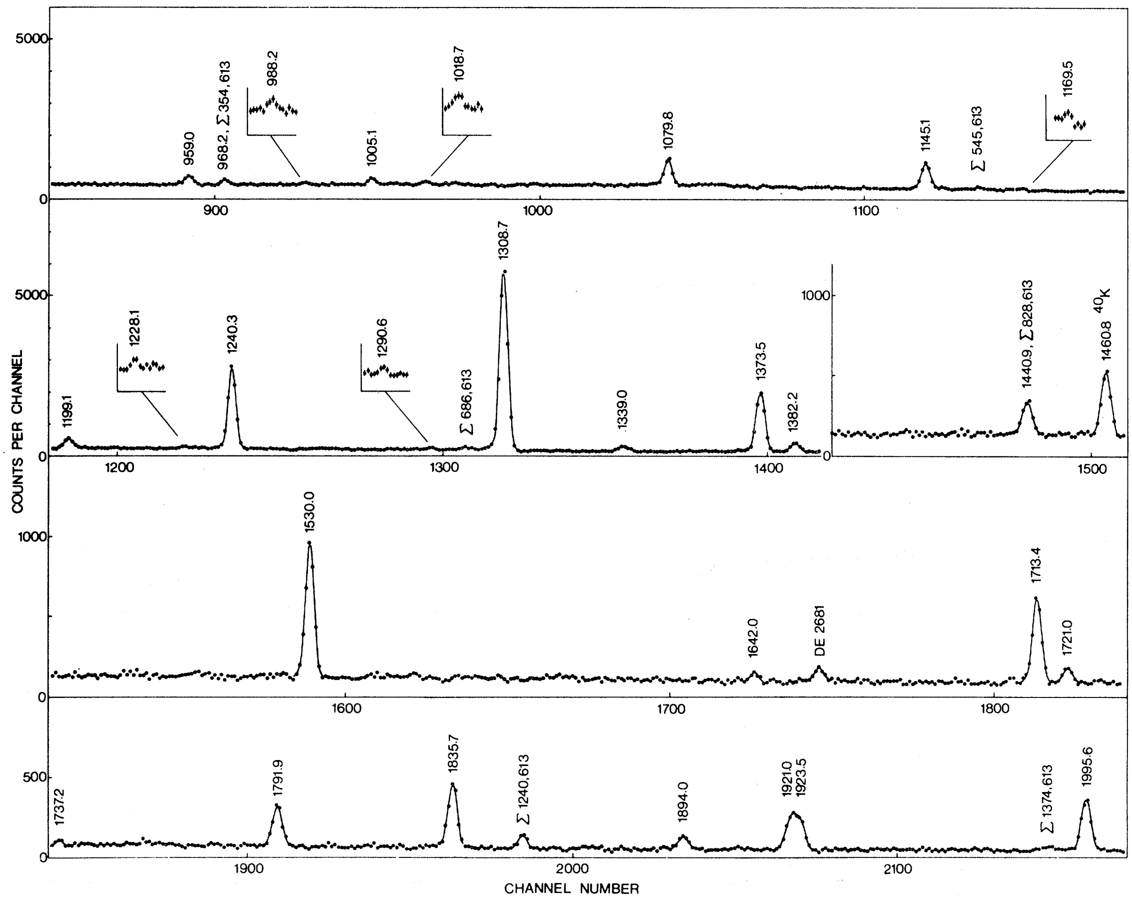

FIG. 1. (*Continued.*)

since no evidence was found for its presence in the spectrum given in Fig. 1. We have not observed the 440- and 2537-keV γ rays which have been shown to deexcite this level in (n,γ) work[8,9] and ^{78}Br decay studies,[10] respectively.

Level at 2647.7 keV. The observation of a 1339.0-keV γ ray in coincidence with the 694.9-keV γ ray establishes a new level at 2647.7 keV. Previously the 1339.0-keV γ ray had been assigned to the decay of the 2838.6-keV level[4] or the 3192-keV level.[3] The latter level has been excluded since our γ-γ coincidence data do not support the suggested placement[3] of the other two transitions with energies of 354 and 1199 keV, which were assigned to this level. In the (n,γ) experiment[8] a 652-keV transition was shown to deexcite this level, but we have not observed a γ ray of this energy.

Level at 2682.0 keV. Transitions with energies of 686.3 and 2068.2 keV have been added to the decay of this level. The first of these is a component of a previously unresolved doublet at 686 keV. The assignment of the 959.0- and 2680.8-keV transitions to this level by Morcos *et al.*[4] is inconsistent with our γ-γ coincidence data.

Level at 2838.6 keV. On the basis of coincidence information, the 1079.8- and 2224.7-keV γ rays and a newly reported 503.7-keV γ ray are included in the deexcitation of this level. Earlier assignment of the 1079.8-keV transition to a 1693-keV level[3,4] or a 3528-keV level[5] leads us to remove both of these levels from the decay scheme. The 1693-keV level[3,4] was established previously by a single transition; the 3528-keV level[5] was shown to deexcite by means of a 2218-keV transition, the correct energy for which is actually 2224.7 keV.

Level at 3144.5 keV. A new γ ray with an energy of 637.1 keV has been added to the decay of this level on the basis of coincidence with transitions deexciting the 2507.7-keV level.

Level at 3229.8 keV. Morcos *et al.*[4] proposed two levels at 3227 and 3232 keV, the former decaying through 722-, 1373-, 1921-, and 2613-keV transi-

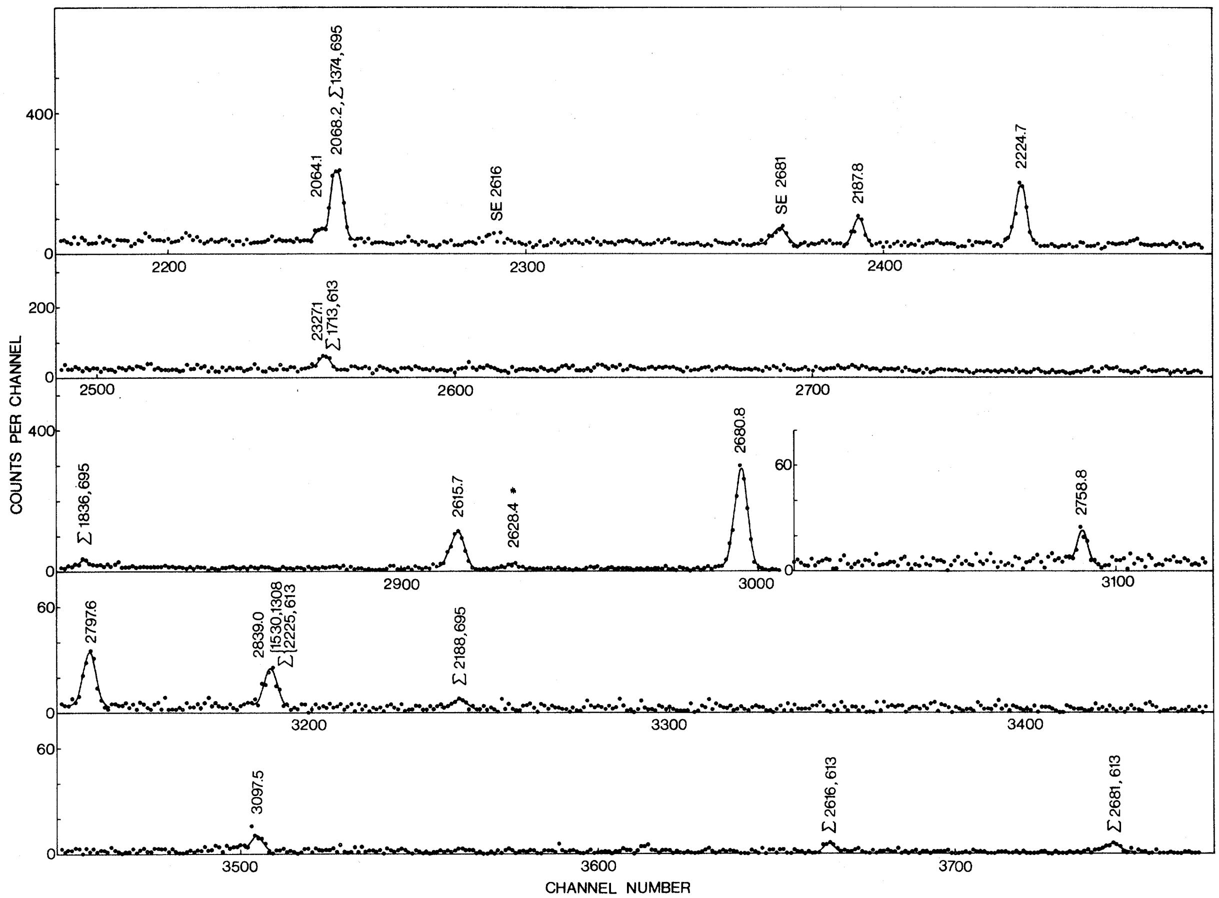

FIG. 1. (*Continued.*)

tions and the latter through 552-, 1923-, and 2616-keV transitions. Our data do not confirm the presence of a 2613-keV γ ray. The coincidence data suggest alternative placements for the 1373.5- and 1923.5-keV γ rays. Using energy sums and coincidence results the 722.4-, 1921.0-, and 2615.7-keV γ rays define a single level at 3229.8 keV. The 551.7-keV γ ray cannot be associated with this level because of a poor energy agreement.

Level at 3294.9 keV. Two newly observed γ rays with energies of 756.9 and 968.2 keV have been assigned to this level; the former placement is based solely on the energy agreement. The 841-keV γ ray assigned to this level by McMillan and Pate[3] was not observed in the present study.

Level at 3372.7 keV. This level has been proposed for the first time from γ-γ coincidence data which establish 2064.1-694.9 and 2758.8-613.8 keV cascades.

Level at 3411.4 keV. A previously unreported γ ray of energy 903.6 keV has been assigned to this level on the basis of the energy agreement. Furthermore, the 2797.6-keV transition is in coincidence with the 613.8-keV γ ray. The previous placement[3,4] of the 2797.6-keV γ ray with a 2797.6-keV level is inconsistent with our γ-γ coincidence data. As a consequence this level has been excluded from the ^{78}As decay scheme.

Level at 3496.4 keV. Based primarily on energy agreements, three newly reported transitions with energies 657.9, 988.2, and 1169.5 keV and the 1737.2-keV γ ray were assigned to this level. In addition, the 2187.8-keV transition forms cascades with transitions from the 1308.6-keV level. The earlier placement[3,4] of this γ ray with a 2798-keV level disagrees with our γ-γ coincidence data.

Level at 3711.4 keV. This level has been established from the observation of the 3097.5-keV γ ray in coincidence with the 613.8-keV γ ray. Paradellis and Hontzeas[5] assigned the 1721.0-keV transition to

TABLE I. Energies and relative intensities of γ rays from the decay of ^{78}As.

McMillan and Pate (1970)		Paradellis and Hontzeas (1970)		Morcos *et al.*[a] (1971)		Fettweis *et al.* (1972)		Peek *et al.*[b] (1972)	Present		Placement
E_γ	I_γ	E_γ	I_γ	E_γ	I_γ	E_γ	I_γ	E_γ	E_γ	I_γ[f]	
				158.4	0.14				156.6 3	0.17 4	2839-2682[c]
				176.3	0.22				174.2 3	0.33 7	2682-2508[c]
354.8 5	0.3			355.8	3.07	354.3 3	3.5 4	356.4	{351.1 2	0.30 3	1854-1503
(doublet)	3.7 4								{354.3 2	3.5 4	2682-2327
									391.0 3	0.23 3	unplaced
									449.8 4	0.15 5	1759-1309[c,d]
463.0 10	0.6 3			462.9	0.84	461.9 5	1.0 2	463.0	462.2 2	1.1 1	3144-2682
									468.8 3	0.18 3	unplaced
									497.0 3	0.34 4	1996-1499
									503.7 2	0.77 7	2839-2335[d]
545.8 5	5.3 6	545.7 3	5.3 3	545.7	6.31	545.4 3	5.6 6	545.0	545.3 1	5.6 4	1854-1309
				552.9	0.56				551.8 3	0.31 6	unplaced
613.5 5	100	614.1 1	100	613.7	100	613.6 3	100	613.2	613.8 1	100	614-0
									637.1 2	0.38 4	3144-2508[d]
									657.9 2	0.50 5	3496-2839[d]
686.7 5	4.0 10	687.2 8	2.5 4	686.6	3.3	686.2 3	3.7 4	685.9	{686.3 2	1.7 2	2682-1996[d]
									{687.5 4	1.2 2	1996-1309
694.7 5	33.0 15	694.8 3	31.4 9	694.9	32.9	695.4 3	34 3	694.1	694.9 1	31 2	1309-614
				722.0	0.35				722.4 2	0.27 3	3230-2508[d]
									756.9 3	0.16 4	3295-2537[c,d]
				786.2	0.22					<0.1	
827.8 5	16.3 7	828.0 6	15.0 30	828.0	17.17	827.6 3	13.8 14	827.1	828.1 1	15 1	2682-1854
841.5 10	0.3 2	842.5 7	2.3 6	842.7	2.16	842.4 5	1.4 2	841.7	842.6 1	2.0 2	2839-1996
843.0 5	1.0 4										
				848.7	0.32					<0.1	
									882.0 2	0.35 6	unplaced
883.0 10	0.8 4			885.5	1.47	884.6 10	1		884.9 2	0.86 8	1499-614
888.6 5	5.0 10	889.3 15	3.6 5	888.3	5.07	889.2 5	1.9 2	887.6	888.7 1	3.9 3	1503-614
									903.6 4	0.15 5	3411-2508[c,d]
959.0 10	1.0 5			958.4	1.12	957.5 10	1		959.0 2	0.86 8	3496-2537
									968.2 4	0.3 1	3295-2327[d]
									988.2 4	0.17 4	3496-2508[c,d]
				1004.5	0.58				1005.1 2	0.59 7	2508-1503
									1018.7 3	0.26 4	2327-1309
1079.5 5	3.5 12	1074.0 4	3.8 4	1079.7	3.78	1080.0 3	3.5 3		1079.8 2	3.0 2	2839-1759
1144.4 5	3.8 5	1144.7 3	3.1 3	1144.8	4.11	1144.5 3	4.0 4		1145.1 1	3.1 2	1759-614

TABLE I. (*Continued.*)

McMillan and Pate (1970)		Paradellis and Hontzeas (1970)		Morcos *et al.*[a] (1971)		Fettweis *et al.* (1972)		Peek *et al.*[b] (1972)	Present		Placement
E_γ	I_γ	E_γ	I_γ	E_γ	I_γ	E_γ	I_γ	E_γ	E_γ	I_γ[f]	
									1169.5 4	0.22 6	3496-2327[c,d]
1198.0 10	1.5 5	1199.0 2	1.3 6	1199.2	2.63	1198.5 10	0.95 40		1199.1 2	1.3 1	2508-1309
		1228.0 10	1.0 2					1227.5	1228.1 4	0.20 10	2537-1309[c]
1239.9 5	12.9 10	1240.5 2	11.0 8	1240.1	15.44	12.39.9 3	10.7 10	1239.2	1240.3 1	11 1	1854-614
				1290.9	0.20				1290.6 6	0.19 6	3144-1854[c]
				1301.1	0.01					<0.1	
1308.3 5	26.6 24	1308.8 2	22.7 10	1308.4	32.01	1308.8 3	19.7 20	1307.5	1308.7 1	24 2	1309-0
1339.0 10	1.0 5			1339.3	1.38	1341.0 10	1		1339.0 2	0.73 10	2648-1309
1373.3 5	10.1 9	1372.5 4	9.0 6	1373.4	13.26	1373.1 3	6.4 2	1372.0	1373.5 1	8.9 6	2682-1309
1382.3 5	1.4 3	1381.0 20	1.2 1	1381.8	2.66	1382.1 3	1.2 1	1381.1	1381.2 2	1.4 1	1996-614
		1440.4 7	0.75 7	1435.9	0.60	1438.6 10	1		1440.9 2	0.6 2	3295-1854
				1475.9	0.22					<0.1	
1529.8 5	5.1 7	1529.5 10	5.0 4	1530.2	7.38	1530.0 3	4.7 5	1529.0	1530.0 1	4.6 3	2839-1309
				1634.9	0.15					<0.1	
				1643.1	0.41			1641.0	1642.0 4	0.29 7	3144-1503[c]
1713.4 5	3.7 4	1714.5 10	4.3 5	1713.9	4.5	1714.3 3	3.4 4	1712.4	1713.4 2	3.3 2	2327-614
		1720.0 20	0.9 2	1721.7	1.26	1720.0 3	1.2 3		1721.0 3	0.59 7	2335-614
				1738.6	0.66				1737.2 4	0.20 5	3496-1759[c,d]
1791.7 5	2.0 5	1791.0 10	2.1 2	1792.7	3.6	1793.0 10	0.8 4	1786.4	1791.9 2	1.8 2	3295-1503
1835.8 5	3.0 4	1838.0 20	3.0 4	1836.7	4.33	1836.0 3	2.6 3	1835.0	1835.7 2	2.7 2	3144-1309
		1893.0 15	1.2 2	1894.6	0.67	1894.7 3	1.4 5		1894.0 2	0.54 6	2508-614
1922.5 5	3.5 3	1921.0 10	3.8 4	1922.1	3.24	1921.6 3	3.0 3	1921.1	1921.0 2	1.5 2	3230-1309[d]
				1924.1	2.94				1923.5 2	1.4 2	2537-614
				1956.0	0.13					<0.1	
1995.6 5	2.5 7	1996.0 10	3.0 3	1997.1	3.77	1995.5 3	2.1 3	1994.8	1995.6 2	2.5 2	1996-0
									2064.1 5	0.21 7	3373-1309[d,e]
2068.4 5	1.1 7	2067.5 10	1.6 1	2068.6	2.26	2068.9 5	1.1 3	2067.0	2068.2 2	1.3 2	2682-614
				2095.3	0.59					<0.1	
2186.3 10	1.0 5	2183.0 15	0.6 1	2188.3	0.94	2188.5 5	1.1 5		2187.8 2	0.67 7	3496-1309
2224.6 5	1.6 3	2218.3 15	1.6 3	2225.9	2.04	2226.1 5	1.4 4	2223.8	2224.7 3	1.7 2	2839-614
								2326.3	2327.1 3	0.2 1	2327-0
2610.0 5	0.5 3			2613.4	0.46					<0.1	
				2616.8	1.15				2615.7 2	1.3 2	3230-614
				2629.3	0.31				2628.4 4	0.15 4	unplaced
2680.5 5	3.5 2	2683.5 20	2.8 3	2681.2	4.88	2682.5 3	2.6 3	2679.0	2680.8 2	3.6 3	3295-614

TABLE I. (*Continued.*)

McMillan and Pate (1970) E_γ	McMillan and Pate (1970) I_γ	Paradellis and Hontzeas (1970) E_γ	Paradellis and Hontzeas (1970) I_γ	Morcos *et al.*[a] (1971) E_γ	Morcos *et al.*[a] (1971) I_γ	Fettweis *et al.* (1972) E_γ	Fettweis *et al.* (1972) I_γ	Peek *et al.*[b] (1972) E_γ	Present E_γ	Present I_γ^{f}	Placement
									2758.8 3	0.21 4	3373-614[d,e]
2797.0 10	0.4 2	2798.5 20	0.3 1	2798.5	0.55	2801.8 10	1		2797.6 2	0.38 5	3411-614
				2839.2	0.26			2836.6	2839.0 3	0.10 5	2839-0
		3103.5 35	0.10 5	3098.7	0.17			3094.9	3097.5 5	0.12 3	3711-614

[a]Uncertainties not given by authors.
[b]Relative intensities and energy uncertaintes not given by authors.
[c]Placement suggested on the basis of level energy differences only. No $\gamma\gamma$ coincidence evidence available because of low intensity.
[d]Placement suggested in the present study.
[e]New level proposed at 3373 keV.
[f]Relative γ intensities. For intensities per 100 decays multiply by 0.52 6.

this level, but our coincidence data do not support this assignment. The proper placement for this γ ray is with the 2334.9-keV level as shown in Fig. 2.

V. SUMMARY

Improved γ-ray energies and high resolution coincidence data have aided in constructing a more consistent and complete level scheme than those proposed in earlier studies of ^{78}As decay. Out of a total of 66 γ rays observed in the present work, 61 have been placed in the proposed decay scheme shown in Fig. 2. The present data have resulted in a revision of the deexcitation modes of each level above the 1502.6-keV level. Moreover, four new levels have been added to the scheme and seven levels proposed earlier have been found to be redundant.

Very few spins and parities of ^{78}Se levels are known with certainty. Values given in Fig. 2 are from a recent compilation[2] and are consistent with the observed β^- branches and γ transitions from the levels concerned. It is obvious that much experimental work involving long term counting is required to establish J^π assignments for ^{78}Se levels and the multipole character of the γ transitions from the levels.

The ^{78}Se nucleus is frequently quoted as a typical example of a nucleus possessing vibrational modes of excitation. Although detailed J^π information is not yet available, some features of a vibrational spectrum are quite obvious. The closely spaced triplet of levels at 1308.6(2^+), 1498.8(0^+), and 1502.6(4^+) keV can be considered as members of a 2q-phonon state. The average energy of this triplet is about 2.3 times the energy of the one q-phonon state at 613.8 keV. The 1758.9-, 1854.0-, 1995.9-keV levels can be associated with the 0^+, 3^+, 2^+, members, respectively, of a 3 q-phonon vibration. The remaining two 4^+, 6^+ members of this excitation are observed in other studies[2] at 2098.7 and 2539.0 keV, respectively. The average energy of this quintet of states is about 3.3 times the 1 phonon gap. The selection rule for transitions among these phonon states appears to work reasonably well.

In a series of papers Lie and Holzwarth[11,12] have carried out extensive calculations on the ^{78}Se nucleus using involved boson expansion methods. All the above mentioned states are very well reproduced by their calculations. Moreover, they predict two additional levels at 2331.0(2^+) and 2357.7(0^+) keV which may correspond to the 2327.4(2^+) and

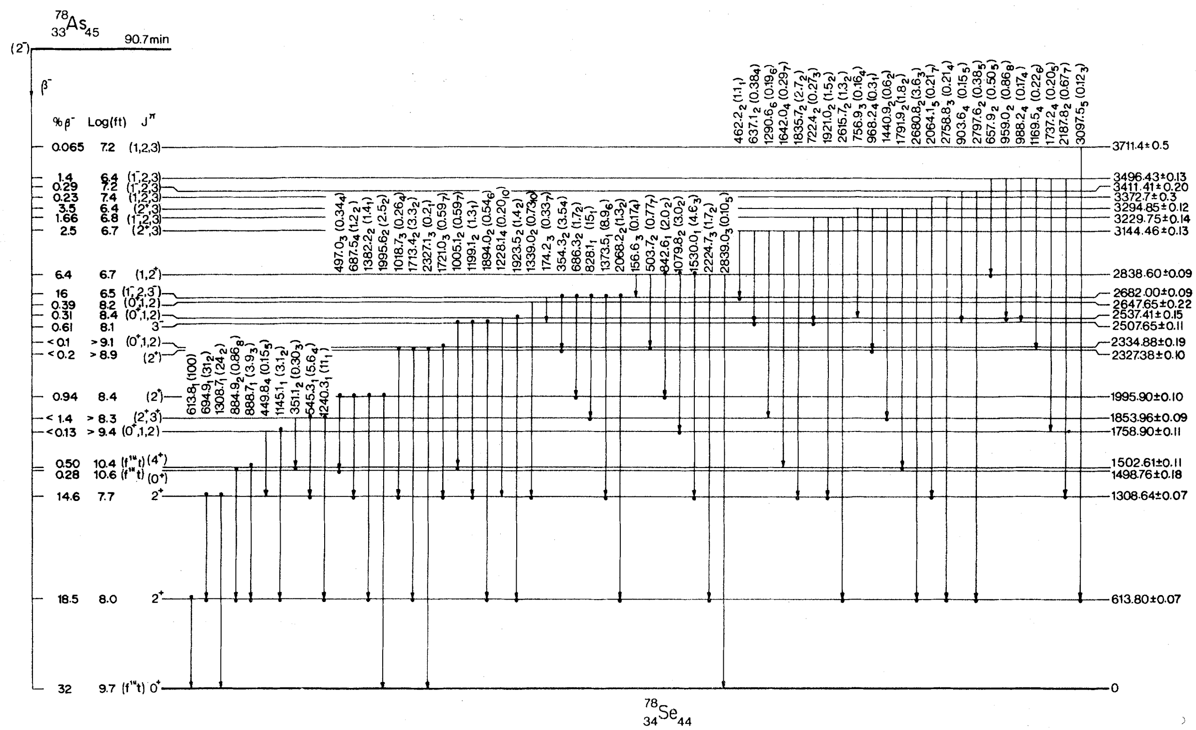

FIG. 2. Proposed decay scheme for ^{78}As. Energies (in keV) and intensities (relative to the intensity of 613.8-keV γ ray taken as 100) and deduced level energies (in keV) are from the present work. The uncertainty on each value is given as a subscript. Dots at the begining and/or at the end of a transition indicate that the γ ray was observed in coincidence with a preceding and/or a subsequent transition, respectively. The β^- branchings and logft values were deduced from the known absolute intensity of the 613.8-keV transition and the γ-ray intensity imbalances at each level. Spins and parities have been taken from a recent compilation (Ref. 2).

TABLE II. Comparison of ratios of reduced transition probabilities [$B(E2)$'s] with theory.

Relevant levels (keV)			Transitions			
E_i	E_f	$E_{f'}$	$J_i\to J_f/J_i\to J_{f'}$	Experimental[a]	Theory (Refs. 11 and 12)	Comments
1309	614	0	$2_2^+\to2_1^+/2_2^+\to0_1^+$	27 ±6	62	$\delta(2_2^+-2_1^+)=2.7$ (Ref. 1)
1499	1309	614	$0_2^+\to2_2^+/0_2^+\to2_1^+$	b	1.5	
1503	1309	614	$4_1^+\to2_2^+/4_1^+\to2_1^+$	b	0.0022	
1759	1309	614	$0_3^+\to2_2^+/0_3^+\to2_1^+$	5 ±2	10	$J^\pi=0^+$ assumed for 1759-keV level
1854	1503	614	$3_1^+\to4_1^+/3_1^+\to2_1^+$	15 ±3	13	$J^\pi=3^+$ assumed for 1854-keV level.
1854	1309	614	$3_1^+\to2_2^+/3_1^+\to2_1^+$	31 ±5	42	All γ transitions assumed as pure $E2$.
1995	1854	0	$2_3^+\to3_1^+/2_3^+\to0_1^+$	b	17	
1995	1759	0	$2_3^+\to0_3^+/2_3^+\to0_1^+$	b	7.0	
1995	1503	0	$2_3^+\to4_1^+/2_3^+\to0_1^+$	c	14	
1995	1499	0	$2_3^+\to0_2^+/2_3^+\to0_1^+$	144 ±30	67	All γ transitions assumed as pure $E2$.
1995	1309	0	$2_3^+\to2_2^+/2_3^+\to0_1^+$	99 ±20	5.3	
1995	614	0	$2_3^+\to2_1^+/2_3^+\to0_1^+$	3.5±0.8	0.68	

[a]Present work.
[b]Theoretical $B(E2)$ ratio predicts a relative transition intensity of 0.0005 which is consistent with the nonobservation of such a transition in the present work.
[c]Theoretical $B(E2)$ ratio predicts an intensity of 0.03 for an unobserved γ ray at 492 keV.

2334.9(0^+) levels shown in Fig. 2. Their predicted values for the static quadrupole moment for the first 2^+ state and $B(E2)$ values for several transitions agree well with the Coulomb excitation measurements of Le Comte *et al.*[1] and Barrette *et al.*[1] In Table II we show a comparison of the deduced $B(E2)$ ratios from our work with the theoretical values.[11,12] With the exception of a few transitions from the 1995-keV level, a general agreement is found between the two sets of values. A measurement of spins of the 1758.9-, 1853.90, and 2334.9-keV levels and the multipole mixing ratios of the γ transitions will have to be made, however, before a more rigorous test of the theory can be carried out.

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[1]R. Le Comte, P. Paradis, J. Barrette, M. Barrette, G. Lamoureux, and S. Monaro, Nucl. Phys. A284, 123 (1977); J. Barrette, M. Barette, G. Lamoureux, and S. Monaro, *ibid.* A235, 154 (1974).

[2]B. Singh and D. A. Viggars, Nucl. Data Sheets (in press).

[3]D. K. McMillan and B. D. Pate, Nucl. Phys. A140, 529 (1970).

[4]N. A. Morcos, T. E. Ward, and P. K. Kuroda, Nucl. Phys. A168, 561 (1971).

[5]T. Paradellis and S. Hontzeas, Nucl. Phys. A142, 204 (1970).

[6]N. F. Peek, W. J. Knox, E. C. May, and S. Jha, Bull. Am. Phys. Soc. 17, 16 (1972).

[7]P. Fettweis and P. del Marmol, Radiochim. Acta 17, 55 (1972).

[8]D. A. McClure, N. S. Kendrick, Jr., and J. W. Lewis III, Georgia Institute of Technology report, 1974 (unpublished).

[9]D. Rabenstein and H. Vonach, Z. Naturforsh. 26a, 458 (1971).

[10]P. F. Hinrichsen, G. Kennedy, and T. Paradellis, Nucl. Phys. A212, 365 (1973).

[11]G. Holzwarth and S. G. Lie, Z. Phys. 249, 332 (1972).

[12]S. G. Lie and G. Holzwarth, Phys. Rev. C 12, 1035 (1975).