Levels in ^{72}Se populated by ^{72}Br

W. E. Collins* and J. H. Hamilton
Physics Department,† *Vanderbilt University, Nashville, Tennessee 37235*

R. L. Robinson, H. J. Kim, and J. L. C. Ford, Jr.
Oak Ridge National Laboratory,‡ *Oak Ridge, Tennessee 37830*
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The level structure of ^{72}Se was investigated via the decay of ^{72}Br produced in the ^{58}Ni (^{16}O,pn) reaction. 32 transitions were assigned to ^{72}Se on the basis of half-life, energy, and/or relative γ-ray yields for different beam energies with 18 transitions confirmed by coincidence data. 32 transitions are placed into the decay scheme which consists of the following levels: 862.0, 2^+; 936.8, 0^+; 1316.7, 2^+; 1636.8, 4^+; 1876.0; 1998.4, 1,2^+; 2150.3 (2^+); 2371.6 (2^+); 2433.2; 2586.2; 2965.6; 3124.1; 3225.9; and 3239.5 keV. The half-life of ^{72}Br was measured to be 1.31± 0.04 min.

[RADIOACTIVITY ^{72}Br; measured $T_{1/2}$,E_γ, I_γ, $\gamma\gamma$ coin. ^{72}Se deduced levels, J, π.]

I. INTRODUCTION

The level properties of nuclei far from the region of β stability are expected to provide new insight into the structure of nuclei. Heavy ions now are offering a promising alternative approach to protons and α particles to selectively produce nuclei far from stability. The energies available with ^{16}O ions from tandem Van de Graaff accelerators are sufficient for probes in lighter mass nuclei. In this paper we show the detailed information on short-lived activities that can be obtained by this technique combined with coincidence spectroscopy.

The low-lying levels in ^{70}Ge and ^{72}Ge are unusual in that they have a first excited 0^+ state just above and just below the first excited 2^+ state, respectively, rather than near twice the 2^+ energy. The properties of levels in neighboring even-even nuclei should provide additional information to clarify the character of the levels in this region. Nolte *et al.*[1] and, independently, Doron and Blann[2] have obtained information on the first three levels of ^{72}Se from $^{58}Ni(^{16}O, pn)^{72}Br$ γ-ray singles studies.

In the present work, singles and coincidence γ-ray studies were carried out with a Ge(Li)-NaI(Tl) detector system to study the levels in ^{72}Se populated by ^{72}Br. The ^{72}Br was produced in the $^{58}Ni(^{16}O, pn)$ reaction. Transitions were identified on the bases of half-lives, energies, and/or γ-ray yields for different beam energies. From the data, 32 transitions were assigned to and placed in the ^{72}Br decay to 14 excited levels in ^{72}Se. Of particular interest is the first excited 0^+ level which is only 75 keV above the first 2^+ level. Preliminary reports of this work appeared earlier.[3]

II. EXPERIMENTAL SETUP AND PROCEDURE

A 1-mg/cm^2 enriched ^{58}Ni target was irradiated with 42- to 46-MeV ^{16}O ions from the Oak Ridge National Laboratory (ORNL) tandem Van de Graaff accelerator. In the singles analysis, a router unit divided the 16000-word memory of the analyzer into seven different segments which will be denoted as banks. Each bank corresponded to ordered time events, i.e., the spectrum accumulated in the nth $T/7$ units of time was stored in the nth 2000-channel group. This procedure was done for the purpose of half-life determinations. After storing in each of seven banks, the irradiation and data collection processes were repeated. The various combinations of ^{16}O energies and bank times used are summarized in Table I.

The target had a separate gold-leaf backing on the side of the target opposite the incident beam. The gold foil stopped the recoil products, while

TABLE I. Values of various parameters for some of the runs utilized in the present work.

Run	^{16}O Energy (MeV)	Bank time (sec)	Number of banks in set
1	42.5	10	6
2	42.5	4000	6
3	42.5	100	6
4	42.0	3000	7
5	46.0	2972	7
6	46.0	59.7	6

the beam passed through the foil to a Faraday cup. For the long bank times, the induced radioactivity was counted at the end of each irradiation by manually removing the sample from the beam chamber and counting in a location with low background. As a result of this procedure most short-lived activities (< 10 min) were not observed in such runs. For short-lived activities, the sample was irradiated for a time T_n in a position where the beam intercepts the target; afterward, the sample was flipped out of the beam to a position between two detectors but still in vacuum where the activity was counted. For the short irradiation, after counting for time T_n, the source reverted back to its initial position and the irradiation-counting process repeated itself.

In the γ-γ coincidence work, a 30-cm^3 Ge(Li) detector and a 7.62-cm × 7.62-cm NaI(Tl) detector were used in a two-parameter experiment utilizing a 512 by 32 configuration. Timing information was obtained by using the crossover and leading-edge time-pickoff methods for the NaI and the Ge(Li) detectors, respectively, with a time-to-amplitude converter and a single-channel analyzer used for coincidence determination. After information was stored in the memory of the analyzer, all data were transferred to an on-line computer and stored on a disk where some of the data reduction was facilitated by use of several programs[4] developed at ORNL. The experimental arrangements are discussed in more detail elsewhere.[5]

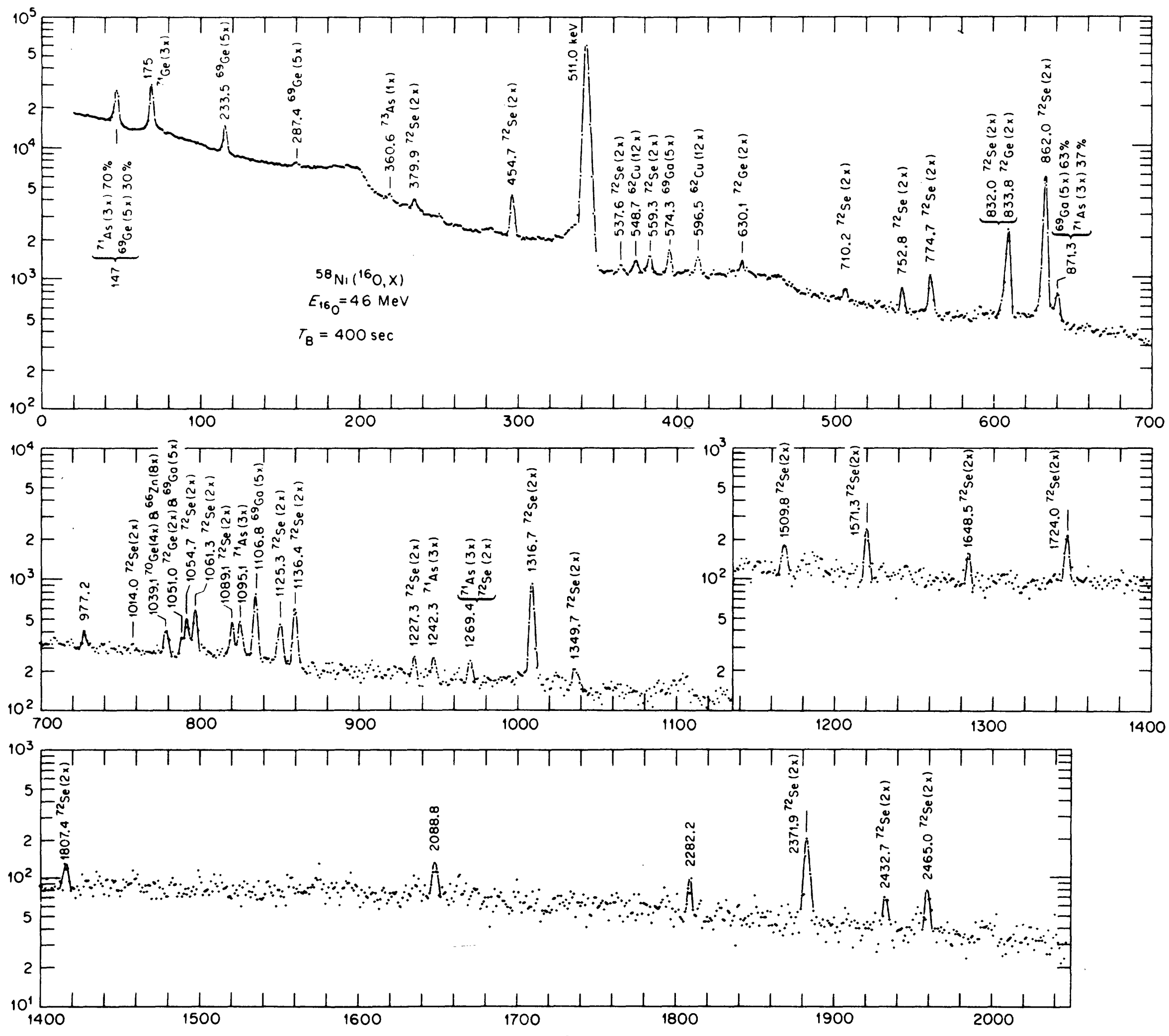

FIG. 1. Germanium singles spectrum taken from first bank of run six. All identifications are given according to product nuclei. The numbers in parentheses indicate how many particles were emitted by the compound nucleus, e.g. (2×) means 2 particles. A few weak high-energy transitions were not identified.

III. EXPERIMENTAL RESULTS

A. Singles analysis

All γ rays were given assignments according to energy and half-life where it was reasonable and possible to do so. A γ-ray spectrum from the first bank of run six is shown in Fig. 1. For several runs with different ^{16}O energies the ratios of various γ-ray intensities with all other γ rays were obtained and compared. If the ratio of a particular γ-ray intensity to another is the same in each of the runs, the γ rays are assumed to be from the same isotope, if, in addition, their half-lives are the same. We identified the primary γ rays associated with the decays of ^{72}Br, ^{62}Zn, ^{69}Ge, ^{70}As, and ^{72}As and these are labeled in Fig. 1.

Each γ ray was checked as a possible unresolved doublet by a comparison of energies and relative intensities with the known transitions[6,7]

TABLE II. γ rays assigned to the decay of ^{72}Br and the basis of such assignment. Also shown are the results of other work and the relative intensities.

Energy (keV)	$T_{1/2}$ (min)	V [a]	I_{relative}	Energy [b] (keV)	I [b]
75 ± 2		x	c		
379.9 ± 0.3	1.7 ± 0.5	x	5.1 ± 0.8		
454.7 ± 0.3	1.3 ± 0.1	xx	18.7 ± 1.1	454.5 ± 0.5	15 ± 5
512 ± 2 [d]	···	x	2.9 ± 1.1 [d]		
537.6 ± 0.3	>0.5	x	1.8 ± 0.6		
559.3 ± 0.3	1.6 ± 0.4	x	3.7 ± 0.4		
710.2 ± 0.4	4^{+21}_{-4}	x	2.3 ± 0.5		
752.8 ± 0.4	1.5 ± 0.3	x	4.2 ± 0.6		
774.8 ± 0.3	1.2 ± 0.2	xx	10.1 ± 0.6		
832 ± 2	···	x	2.9 ± 1.1		
862.0 ± 0.2	1.31 ± 0.04	xx	100	862.3 ± 0.5	100
1014.0 ± 0.8		x	1.0 ± 0.5		
1054.7 ± 0.3	1.6 ± 0.4	x	5.3 ± 0.9		
1061.6 ± 0.3	1.1 ± 0.2	x	7.9 ± 0.7		
1089.2 ± 0.3 [e]	1.4 ± 0.4	xx	4.5 ± 0.5 [e]		
1125.1 ± 0.3	1.1 ± 0.3	xx	7.6 ± 0.8		
1136.4 ± 0.4	1.4 ± 0.1	xx	10.0 ± 1.0		
1227.3 ± 0.4	$1.6^{+1.5}_{-0.6}$	x	1.5 ± 0.6		
1269.5 ± 0.5	$3.6^{+2.0}_{-2.7}$	x	1.2 ± 0.6		
1316.7 ± 0.3	1.3 ± 0.1	xx	24.6 ± 1.5	1316.6 ± 0.5	18 ± 5
1349.9 ± 0.3	1.0 ± 0.2	x	3.2 ± 0.6		
1433.6 ± 1.0	···	x	1.4 ± 0.5		
1509.8 ± 0.4	1.1 ± 0.6	x	4.7 ± 0.8		
1571.3 ± 0.4	1.7 ± 0.3	x	5.4 ± 0.4		
1648.5 ± 0.5	$2.3^{+5.0}_{-1.1}$	x	2.2 ± 0.6		
1724.0 ± 0.5	1.4 ± 0.2	x	4.9 ± 0.4		
1807.4 ± 0.6	$0.6^{+0.6}_{-0.2}$	x	2.5 ± 0.5		
1909.4 ± 0.7	···	x	1.9 ± 0.5		
2150.7 ± 1.0	$1.4^{+2.8}_{-0.6}$	x	1.4 ± 0.4		
2371.9 ± 0.7	1.4 ± 0.1	x	10.7 ± 1.1		
2432.7 ± 0.8	···	x	1.8 ± 0.4		
2465.0 ± 0.8	$1.8^{+4.0}_{-0.7}$	x	1.4 ± 0.4		

[a] One x indicates that the γ ray was placed in the decay scheme. Two x's indicate that the γ ray also satisfied the requirements of constant relative cross sections versus beam energy. Meaningful information on γ-ray yield versus beam energy could only be obtained for the more intense transitions.

[b] From Ref. 2

[c] This intensity was not obtained because of the lack of an efficiency curve at this low energy and the complexity of the peak.

[d] This γ ray is based on an energy fit and intensity balance in coincidence data and is thus considered tentative. It is masked by the 511-keV annihilation radiation.

[e] Possible doublet or triplet, see discussions of the 2965.6- and 3239.5-keV levels.

of every isotope identified in the experiment.

The energies and intensities from the singles analysis for γ rays in the decay of ^{72}Br to ^{72}Se are given in Table II. The energies in Table II were obtained by averaging the results obtained from internal and external calibration techniques. Both methods yielded results that were consistent within experimental error. The relative efficiency of the detector was determined with an average of 3%. Even a more conservative error of 5% would have left essentially unchanged all errors but those of the three strongest transitions and for their energy range the 3% is quite good.

B. Coincidence analysis

The coincidence work was used to construct a level scheme for ^{72}Se. Because of the poor resolution of the NaI detector in the coincidence system, it is very important to determine quantitatively the ratio of the number of events of γ_1 in coincidence with γ_2 (the gating event of interest) to γ_2. This is necessary because of the possibility of doublets within each peak on the NaI(Tl) side. The following coincidence ratio q was calculated for every coincidence relation; however, since a complete table would be so long, only selected

TABLE III. Summary of coincidence results in the decay of ^{72}Br where the gate energy selected from the Ge(Li) spectrum is given across the top. The 455-keV gate was from the first run and all others from the second. Each NaI photopeak in the spectra coincidence with a Ge(Li) gate signal would be spread over several channels. The entry is made in the group where the photopeak has its maximum intensity, e.g. in the 559-keV gate a photopeak has its maximum in group 5 which is where the 710-keV γ ray peaks.

Group [a]	E_γ (keV)	455	559	710	753	775	862 [b]	1055	1062	1089	1125	1136	1317	1510	1571	1724
1.	559			S												
2.																
3.																
4.	710															
5.	710, 753		VS													
6.	710, 753, 775							M		S				M		
7.	753, 775, 832						VS			S						
8.	775, 832, 862									S			S			
9.	832, 862	S	VS	S	S	VS		S	S	S	S	S		S	S	S
10.	862															
11.																
12.																
13.	1055, 1062		P		W						M		M			
14.	1055, 1062, 1089						W						M			
15.	1055, 1062, 1089, 1125		P			P					M					
16.	1062, 1089, 1125, 1136						M		M			S				
17.	1125, 1136															
18.	1227															
19.	1227, 1270												W			
20.	1227, 1270, 1317									M						
21.	1270, 1317, 1350		S	M	W			S								
22.	1317, 1350															
23.	1317, 1350, 1434										P					
24.	1434								W			P				
25.	1434, 1510															
26.	1434, 1510															
27.	1510, 1571															
28.	1571				P										P	
29.	1571, 1648		P							P			W			
30.	1648															
31.	1648, 1724															
32.	1724															

[a] The group number is the channel number for the NaI(Tl) projection of the γ-ray spectra. If part of a γ-ray peak (within its FWHM) assigned to the decay of ^{72}Br falls in a group, it is listed by the correspoding group.

[b] The γ rays in coincidence with this gate are more clearly seen in Fig. 4.

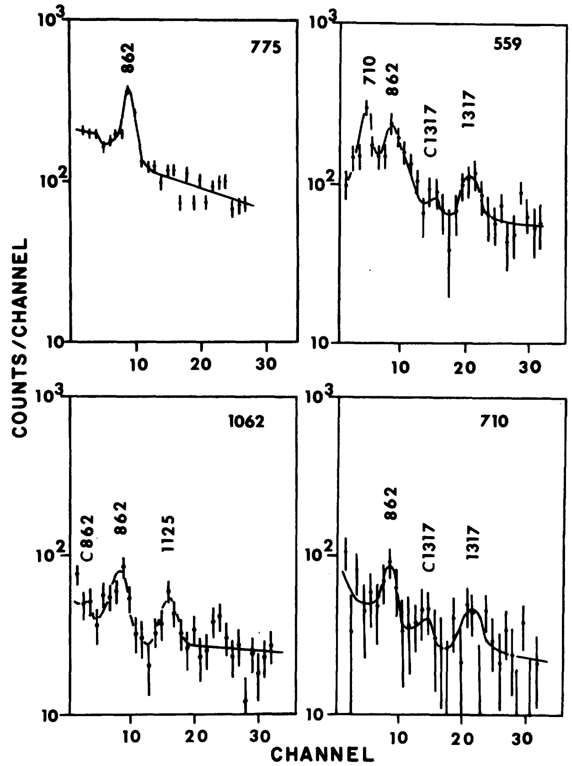

FIG. 2. Semilog plots of NaI spectrum of ^{72}Br in coincidence with the 559-, 710-, 775-, and 1062-keV photopeak gates in the Ge(Li) spectrum. The C1317 stands for the Compton edge.

q's are given in the text when they are particularly important: $q = P/[ce\Omega W(\theta)]$ where q = [number of events of γ_1 in coincidence with γ_2]/[number of events of γ_2(gate)]; P is the coincidence peak area of γ_1; $e\Omega$ is the correction for peak efficiency and solid angle; $W(\theta)$ is a correction for angular correlation effects; and c is the total number of gate counts of γ_2.

Absorption and chance corrections were negligible. Since no correlation functions are known, $W(\theta)$ was taken to be one. With the large statistical error limits on the q's (20–80%) and smearing out of $W(\theta)$ by the close geometry used, the small errors from correlational effects will not change any conclusions. Two coincidence runs were made. The first covered the range of 400–1700 keV and the second from 530 to 1750 keV. A summary of the coincidence experiment data is given in Table III. With the exception of the 455-keV gate, all the data are from the second run. The presence of a γ ray in the spectrum coincident with the gating γ ray is indicated in the table as one of the following entries: VS, S, M, W, and P; these symbols for very strong, strong, medium, weak, and possible, respectively, represent the γ-ray strengths only with respect to other γ rays in the same gate spectrum. Transitions labeled possible are suggested but not definitely established by the data. Some of the gate spectra with Compton background coincidences subtracted are shown in Figs. 2–4. These and others were used to construct the decay scheme in Fig. 5. Figures 2 and 3 are from gates on the Ge(Li) side while Fig. 4 is from a gate on the 862-keV NaI peak.

IV. DISCUSSION OF LEVELS

In constructing the level scheme, γ-ray energy sums supplied additional cross checks and new information. The level energies via two paths were required to differ by less than 0.8 keV except for the 2465.0 ± 0.8-keV transition which differs from the adopted value by 1.1 ± 1.0 keV.

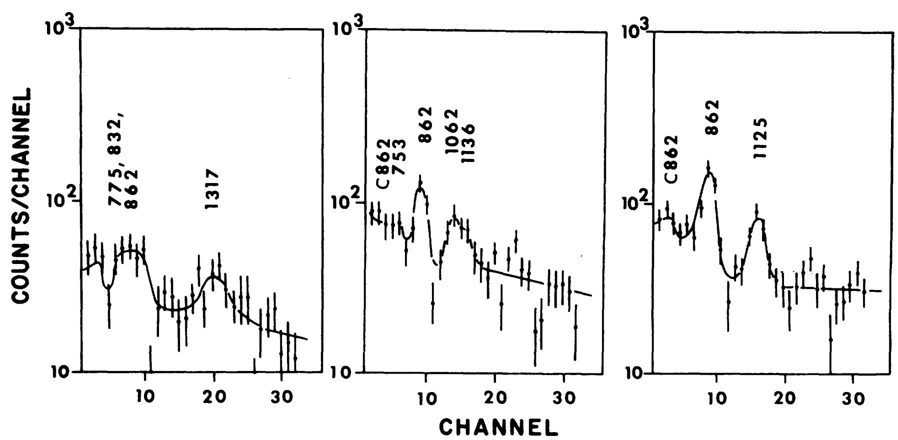

FIG. 3. Semilog plots of NaI spectrum of ^{72}Br in coincidence with the 1089-, 1125-, and 1136-keV photopeak gates in the Ge(Li) spectrum where the 1089 gate is on the left and 1136 on the right.

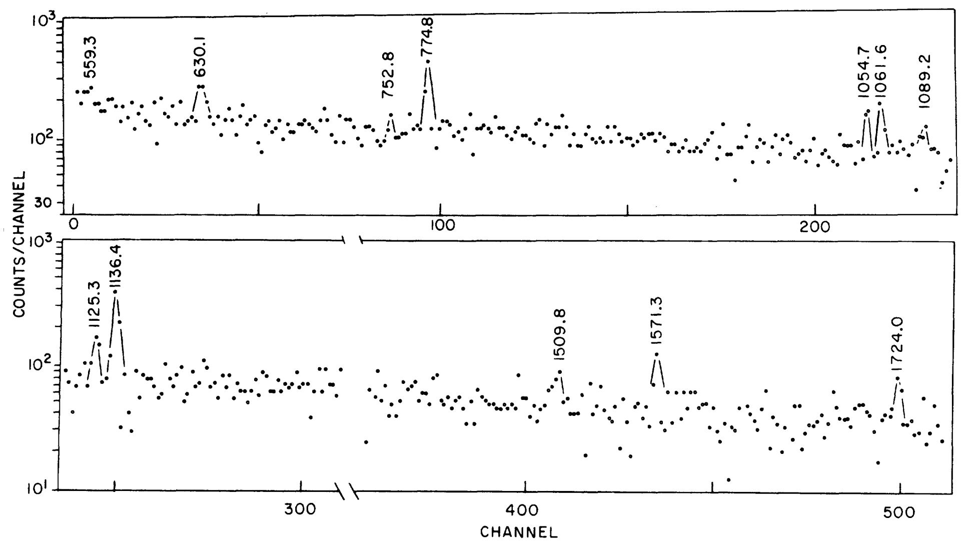

FIG. 4. Ge(Li) spectrum in coincidence with the 862-keV NaI(Tl) gate. The 630.1-keV γ ray is from the decay of ^{72}As in coincidence with the 834-keV transition. Other labeled γ rays are assigned to the decay of ^{72}Br.

TABLE IV. The energy-sum relationships used to determine the energies of levels in ^{72}Se.

Energy sums (keV)	Adopted level energy (keV)
862.0 ± 0.2	862.0 ± 0.2
(1998.4 ± 0.4) − (1061.6 ± 0.3) = 936.8 ± 0.5	
(1316.7 ± 0.3) − (379.9 ± 0.3) = 936.8 ± 0.4	936.8 ± 0.3
(454.7 ± 0.3) + (862.0 ± 0.2) = 1316.7 ± 0.4	
1316.7 ± 0.3	1316.7 ± 0.3
(774.8 ± 0.3) + (862.0 ± 0.2) = 1636.8 ± 0.4	1636.8 ± 0.4
(559.3 ± 0.3) + (1316.7 ± 0.3) = 1876.0 ± 0.4	1876.0 ± 0.4
(1136.4 ± 0.4) + (862.0 ± 0.2) = 1998.4 ± 0.5	1998.4 ± 0.5
(832 ± 2) + (1316.7 ± 0.3) = 2148.7 ± 2.0	
2150.7 ± 1.0	2150.3 ± 0.9
(1054.7 ± 0.3) + (1316.7 ± 0.3) = 2371.4 ± 0.4	
(1509.8 ± 0.4) + (862.0 ± 0.2) = 2371.8 ± 0.4	
2371.9 ± 0.6	2371.6 ± 0.3
(1571.3 ± 0.4) + (862.0 ± 0.2) = 2433.3 ± 0.4	
2432.7 ± 1.	2433.2 ± 0.4
(710.2 ± 0.4) + (1876.0 ± 0.4) = 2586.2 ± 0.6	
(1269.5 ± 0.5) + (1316.7 ± 0.3) = 2586.2 ± 0.6	
(1724.0 ± 0.5) + (862.0 ± 0.2) = 2586.0 ± 0.5	2586.2 ± 0.4
(379.9 ± 0.3) + (2586.2 ± 0.4) = 2966.1 ± 0.4	
(1089.2 ± 0.3) + (1876.0 ± 0.4) = 2965.2 ± 0.4	
(1648.5 ± 0.5) + (1316.7 ± 0.3) = 2965.2 ± 0.6	2965.6 ± 0.3
(537.6 ± 0.3) + (2586.2 ± 0.4) = 3123.8 ± 0.6	
(752.8 ± 0.4) + (2371.6 ± 0.3) = 3124.4 ± 0.5	
(1125.3 ± 0.4) + (1998.4 ± 0.5) = 3123.7 ± 0.6	
(1807.8 ± 0.6) + (1316.7 ± 0.3) = 3124.5 ± 0.6	3124.1 ± 0.3
(1227.3 ± 0.4) + (1998.4 ± 0.4) = 3225.7 ± 0.6	
(1349.9 ± 0.3) + (1876.0 ± 0.4) = 3225.9 ± 0.5	
(1909.4 ± 0.7) + (1316.7 ± 0.3) = 3226.1 ± 0.7	3225.9 ± 0.4
(1089.2 ± 0.4) + (2150.3 ± 0.9) = 3239.5 ± 1.0	3239.5 ± 1.0

Table IV lists the energy sums and the adopted level energies obtained from weighted averages of the sums. Table V gives the β feedings and the log*ft* values. Although the annihilation peak is complex, an analysis of it showed the positron feeding to the ground state is weak (< 10% feeding) if present at all. The cross-section work[5] likewise yields the same conclusion regarding the ground-state feeding. Since β decay is observed to both 2^+ and 4^+ levels, it is assumed there is no decay to the ground state or the 937-keV 0^+ level.

The spin of ^{72}Br has been proposed as 2^+ based on the β decay to the first two 2^+ states.[2] The β decay to the 4^+ level, however, now indicates a spin of 3. The log*ft* of about 6.4 for decay to the first 2^+ state is consistent with even or odd parity. Very recently two groups[8,9] have observed the decay of 0^+ ^{72}Kr to ^{72}Br with conflicting reports of ~50%[9] and ~0%[8] β feeding between these ground states. These data may be explained by a low-energy isomer in ^{72}Br. The half-life of ^{72}Br was measured to be 1.31 ± 0.04 min from the decay of the 862.0-keV transition.

A. Levels previously reported

1. 862.0 ± 0.2-keV level

It is known from (α, $xn\gamma$) studies[10] and ^{58}Ni(^{16}O, pn) studies[1] that the first excited 2^+ state of ^{72}Se is at 862 keV. This assignment is substantiated by this experiment.

2. *1316.7 ± 0.3-keV level*

This level has been observed only in the ^{72}Br studies.[1,2] The 455-, 862-, and 1317-keV Ge(Li) gates show that the 454.7-keV γ ray feeds the 862.0-keV level and the 1316.7-keV one feeds the ground state. This level has been assigned[1,2] as the second 2^+ state on the basis of β decay to it. Although the β-decay argument does not hold now that β decay to the 4^+ 1636.7-keV level is seen too, the decay characteristics strongly support a 2^+ assignment.

3. *1636.8 ± 0.4-keV level*

This level was reported[1,2,10] previously. Only a 774.8-keV γ ray is observed to depopulate it. The 775-keV Ge(Li) gate (Fig. 2) shows that (100 ± 20)% of the 775-keV γ-ray intensity goes to the 862-keV level and shows no other γ ray above 550 keV feeding this level. There are no strong low-energy γ rays to feed the level but some feeding via a 512-keV transition is deduced from other coincidence data (Sec. B 11). Also the 774.8-keV γ ray is the strongest one in the 862-

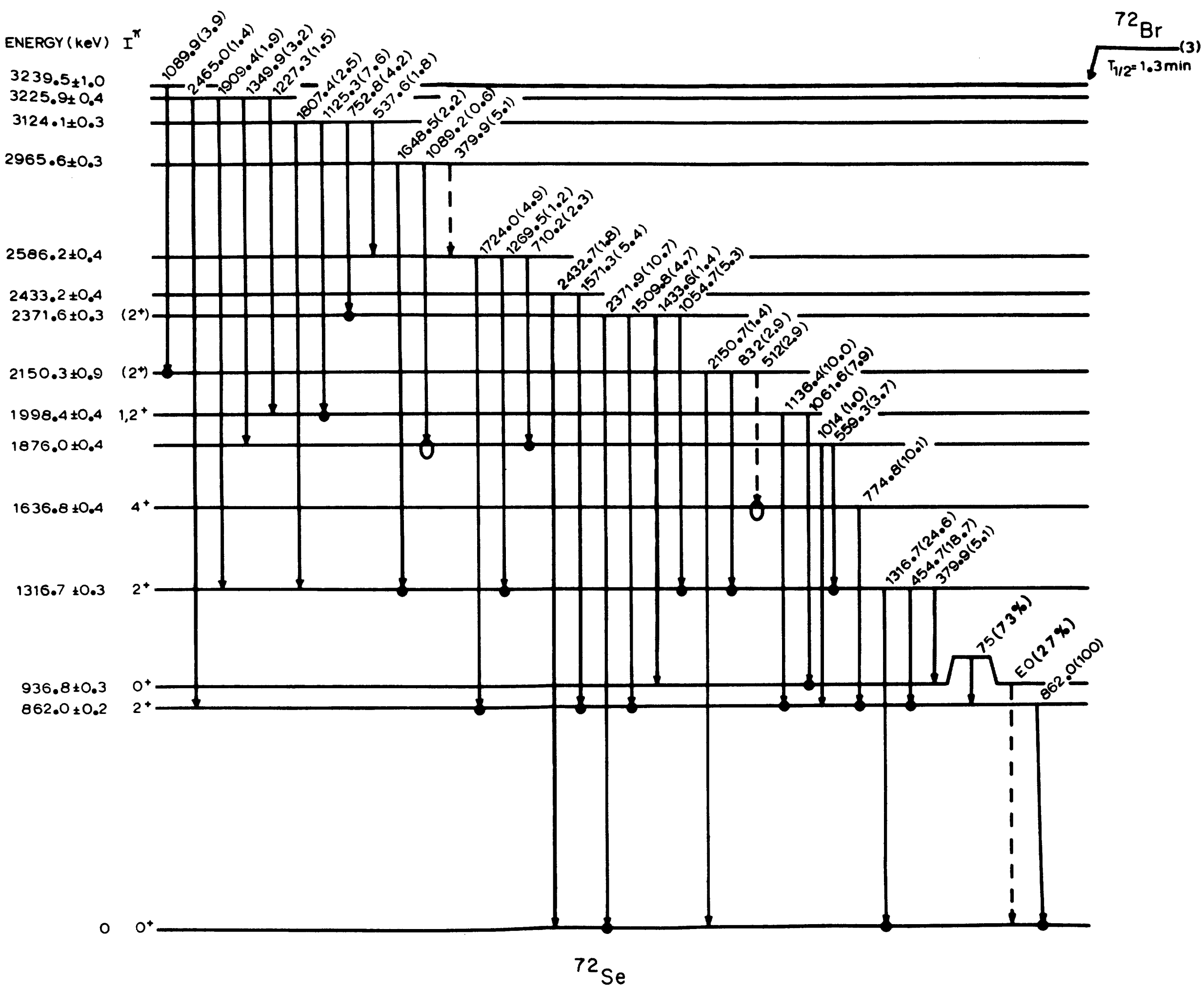

FIG. 5. Proposed level scheme for ^{72}Se. A closed circle indicates the placement was verified by coincidence data and an open circle that coincidence spectra give weak evidence for such placement. The 379.9-keV transition fits in two places and the 512-keV transition is only tentatively assigned. 11 of the levels are based on strong coincidence evidence. The 1876.0-keV level could be moved up with the 710-keV transition lower than the 559.3-keV one but this seems less likely (see text). The 3225.9-keV level is based on four energy fits and the 3239.5-keV level is forced by the 1089-keV coincidence data though this argument is complex. The measured (Ref. 12) branching of the 75- and 937-keV transitions is given.

keV gate. Thus, the primary feeding to this level is via β decay. From γ-ray angular distribution work,[10,11] this level has been assigned a spin of 4 and even parity.

B. New levels observed in the present work

1. 936.8 ± 0.3-keV level

This level is proposed primarily to explain the 1062-keV coincidence data. The 1061.6- and 1125.1-keV γ rays are shown clearly to be in coincidence from the 1125- and 1062-keV gates (see Figs. 2 and 3). Since the 1061.6-keV γ ray is not observed in the 1136-keV gate, then either the 1125.1-keV transition is higher in the decay scheme than the 1061.6-keV one or it is a doublet.

In the 1136-keV Ge(Li) gate, I_γ of the 1125.1-keV γ ray coincident with the 1136.4-keV transition is (44 ± 20)% of I_γ of the 1136.4-keV γ ray. However, in the singles data, I_{1125} is (80 ± 12)% of I_{1136}. The 1125-keV Ge(Li) gate indicates within 1σ that at most 50% of the 1125-keV transition

TABLE V. Positron feedings obtained from relative γ-ray intensities and the measured (Ref. 12) $E0$ branching of the 936.8-keV level with no β feeding to the ground and 936.8-keV states and logft values calculated with the aid of tables (Ref. 6) from these feedings for an estimated (Ref. 2) decay energy of 9.2 MeV. The ground-state feeding was measured to be less than 10% and assigned to be essentially zero on the basis of β decays to known 2^+ and 4^+ levels as shown below. Feeding of the 936.8-keV 0^+ state is likewise assumed to be zero as for the ground state, since the 75-keV γ-ray intensity was not measured, and is now measured (Ref. 13) to be (0 ± 3)%. The dashed 379.9-keV transition was ignored. The γ intensity out of the 1876.0-keV level is slightly less than the intensity into the level so essentially no β feeding for this level is assumed.

Level (keV)	β feeding (%)	logft
0	0	
862.0	23.2 ± 2.8	6.7
936.8	0	
1316.7	20.0 ± 2.0	6.7
1636.8	5.0 ± 0.9	7.1
1876.0	−1.0 ± 0.7	
1998.4	6.1 ± 1.1	7.0
2150.3	2.3 ± 1.3	7.3
2371.6	12.4 ± 1.3	6.5
2433.2	5.0 ± 0.4	6.9
2586.2	4.6 ± 0.8	6.8
2965.6	1.9 ± 0.6	7.1
3124.1	11.2 ± 0.9	6.3
3225.9	5.6 ± 0.8	6.5
3239.5	2.7 ± 0.5	6.9

depopulates via the 1136-keV γ ray. Likewise quantitative analysis of the 1062- and 1125-keV gates shows that there is sizable branching in the 1062-1125-keV cascade. Also, the 1061.6- and 1136.4-keV γ rays are of nearly equal intensity in the 1125-keV gate. Furthermore, much of the 1061.6-keV γ intensity and somewhat less of the 1125.1-keV γ intensity are not seen in the 862-keV gate. From Fig. 4 one finds $I_\gamma(1061)/I_\gamma(1136) = 0.37 \pm 0.11$ in the 862-keV gate while their γ-ray singles ratio is 0.79 ± 0.11. Either these γ rays have alternate feeding to the ground state and/or they feed a level with an appreciable lifetime. No alternate γ-ray feeding to the ground state for these transitions was observed.

There exists no evidence that the 1125.1-keV γ ray is a doublet in the Ge(Li) singles. To explain the observed coincidence spectra we were led to postulate a 936.8-keV level. Other transitions involving this state could be expected and such are seen. The 75-keV γ ray, which is seen as part of a doublet where the stronger component is the lead x ray, can feed the 862-keV 2^+ state. The weak 1433.6-keV γ ray can depopulate the 2371.6-keV level. The 379.9-keV transition, which has two placements in the decay scheme, could depopulate the 1316.7-keV 2^+ state to the 936.8-keV level. Recent in-beam work[12] has shown that most of the 379.9-keV intensity does feed the 936.8-keV level. Our delayed coincidence work[12,13] where both the prompt and delayed γ-ray coincidence spectra were recorded with a resolving time of 7ns, also verifies our conclusion regarding the placement of the 1061.6-keV transition and the 936.8-keV level. In that work[12] the ratio of the 937-keV transition $E0$ electron intensity to the 75-keV total transition intensity was measured to be 0.37 ± 0.23. Other independent evidence for a state at this energy now comes from in-beam conversion-electron work[14] in which conversion electrons of a 937-keV transition were observed with no corresponding γ ray. Thus a 0^+ assignment is made to this level.

2. 1876.0 ± 0.4-keV level

The 559-keV γ coincidence data along with the singles intensities establish this level. The 599- and 710-keV gates establish a strong 559-710-keV coincidence relation. These two γ rays energetically sum to the 1316.7-2586.2-keV level difference. While the coincidence data cannot decide which transition is the upper one, the order is suggested from the singles intensities because I_{559} is greater than I_{710} in the singles spectrum and by the placement of other transitions. A weak 1014.0-keV transition can depopulate and a 1349.9 keV one populate this level on the basis of an energy fit. Also there is weak coincidence evidence for population via a 1089.2-keV transition from an established level. Of course, the intensity balance could be altered by one or two transitions with intensities less than 1 unit which would have been too weak to be observed. However, the placement of the 710-keV transition as lower would not lead to the placement of any other known transitions. Thus the choice of the 559.3-keV transition as lower is favored.

3. *1998.4 ± 0.4-keV level*

The level is established by the 1136-keV gate (Fig. 3) where the 862-keV γ ray ($q = 1.07 \pm 0.23$) is clearly the strongest seen in the coincidence spectrum. The 1061.6-keV transition placement was discussed earlier. There is an unassigned 2000.1 ± 1.1-keV γ ray ($I_\gamma \lesssim 1$), but it is highly questionable that it depopulates the 1998.8-keV level. γ decays to 0^+ and 2^+ levels indicate $J^\pi = 1^\pm, 2^+$.

4. *2150.3 ± 0.9-keV level*

This level is based primarily upon a strong peak about 832 keV with $I_\gamma = 3.8 \pm 1.0$ units in the Ge(Li) 1317-keV gate. From the 1317-keV NaI gate, I_γ of 1.5 ± 1.2 units is obtained. In the singles spectra, this γ ray is completely masked by a very strong 834-keV one from ^{72}As. This level allows the placement of transitions of 512 and 2150.7 keV. Arguments for the existence and intensity of the 512- and 2150.7-keV γ rays are further substantiated by the coincidence spectrum of the 1089-keV gate discussed in Sec. B 11. The 512-keV transition in the singles spectra is masked by annihilation radiation. The γ decays indicate $J^\pi = 2^+$. Since the 512-keV transition is somewhat tentative this assignment is likewise tentative and shown in parenthesis.

5. *2371.6 ± 0.3-keV level*

Qualitative analysis of the gates on the 1055- and 1510-keV transitions establish that they feed directly to the 1316.7- and 862.0-keV levels. These feedings are direct. Indirect feedings by transitions outside the range of the coincidence spectra are excluded since only the 2371.9-keV transition has sufficient intensity. The 2371.9 keV is established as a ground-state transition from this level by a quantitative analysis of the Ge(Li) 753- and NaI 862-keV gates. This level allows the placement of the 1433.6-keV transition. The γ-decay modes yield $J^\pi = 1^\pm, 2^+$, with the 2^+ favored by the log*ft* and systematics.

6. *2433.4 ± 0.4-keV level*

The 1571- and 862-keV gates establish that the 1571.3-keV γ ray terminates at the 862.0-keV level, since there are no transitions with sufficient intensity for intermediate placement. The 2432.7-keV γ ray is assigned as a ground-state transition although its $T_{1/2}$ is somewhat large but with a large uncertainty.

7. *2586.2 ± 0.4-keV level*

The 862.0-keV γ ray is the only identifiable peak in the 1724-keV gate with $q = 1.0 \pm 0.35$. With no unplaced transitions outside the coincidence range, the 1723.9-keV γ ray directly feeds the 862.0-keV level as confirmed by the 862-keV NaI gate. There is weak evidence in the 1317-keV NaI gate for the placement of the 1269.5 γ ray. The 710.2-keV γ ray depopulates this level on the basis of the coincidence data to the 1876.3-keV level. (See Sec. B 2.)

8. *2965.6 ± 0.3-keV level*

This level is established by the 1648.5-keV γ ray in the 1317-keV gate. This level allows the placement of the 1089.2- and 379.9-keV transitions, although the latter has an alternate placement (see B 1). However, the 559-keV gate indicates the intensity of the 1089.2-keV γ ray depopulating such a level is only 0.6 ± 0.5. Part of the Compton edge of the 1316.7-keV transition falls under the 1089-keV peak. Therefore, it is possible that there is no 1089-keV γ ray depopulating the level at all. It should also be noted that the intensity of the 1648.5-keV γ ray in coincidence with the 1316.7-keV one nearly overlaps zero within 2σ, but is what one expects on the basis of the singles intensities.

9. *3124.1 ± 0.3-keV level*

This level was introduced to explain the 1125-1136-keV coincidence data. The fact the 1125.1-keV transition is the next strongest γ ray in the 1136-keV gate suggests that it feeds the state from which the 1136.4-keV γ ray depopulates. Assuming the feeding is direct, one is able to place the 537.6-, 752.8-, and 1807.4-keV γ rays, all of which have half-lives that are consistent with the decay of ^{72}Br. Qualitative analysis of the 753-keV gate supports this placement with substantial ground-state feeding from the 2371.6-keV state. In the 1054-keV gate, the 752.8-keV γ ray is seen weakly while in the 1510-keV gate it is seen with very poor statistics.

10. 3225.9 ± 0.4-keV level

The existence of this level is based solely on energy sums, which allow the placement of the remaining four unplaced transitions. The state is somewhat tentative since none of the γ rays from the level are assigned on the basis of coincidence measurements, though the assignments are not inconsistent with the coincidence work.

11. 3239.5 ± 1.0-keV level

This level is based mainly on the coincidences that involve the 1089.2-keV transition. There exist two or three peaks about 800 keV in the 1089-keV gate which are unresolved (Fig. 3). The data certainly show coincidences with one of the 710.2-, 752.8-, or 774.8-keV transitions and with the 862-keV one. The 832-keV transition is also indicated by the breadth of the 800-keV peak and by the presence of the 1316.7-keV transition. Other coincidence data rule out the 710.2- and 752.8-keV transitions. The 2150.3-keV level allows one to explain the unresolved 800-keV γ rays if one postulates a 512-keV transition which would be masked by annihilation radiation. The unresolved 800-keV γ rays have a q value of 0.79 ± 0.35, which is consistent with the intensities assigned to the 862.0-, 832-, and 774.8-keV γ rays in the proposed decay scheme. The q value for the 1316.7-keV γ ray in the 1089-keV gate is 0.28 ± 0.15, which indicates that other transitions must depopulate the 2150.3-keV level or the 1089.2-keV transition must be a multiplet. Both the 862- and 1317-keV NaI gates yield an intensity for the 1089.2-keV γ ray of about 2.0 units. Earlier possibly 0.6 of the 4.5 units of the 1089.2-keV transition were assigned, leaving 3.9 units to depopulate the 3239.5-keV level. The presence of the 1089.2-keV transition in both the 862- and 1317-keV gates requires that the 3.9 units be split to yield a 1089.2-keV triplet with the third transition feeding the 1636.8-keV level or requires the 512-keV transition feed the 1636.8-keV level. This latter choice does not require an additional new level at 2726 keV as the split would do and is more consistent with the broad 800-keV peak in the 1089-keV gate, so it is preferred. With the assignment of a 50:50 branching for the 832- and 512-keV γ rays based on the 862- and 1317-keV gates showing equal 1089.2-keV γ intensity, the data of the three coincidence spectra agree.

V. DISCUSSION

Possible interpretations of the levels in ^{72}Se and comparisons with neighboring nuclei are given in our next papers.[12,13]

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*Present address: Physics Department, Southern University, Baton Rouge, Louisiana.

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