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A study on the decay of ^{72}As*

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The excited states of the ^{72}Ge nucleus were investigated in radioactive decay of ^{72}As. Three new transitions with 1996.58, 2125.59 and 2255.49keV have been found for the first time. One γ-ray with 912.09keV has been placed in the decay scheme for the first time, and the placement of 1938.88, 2116.79, 2785.59, 2833.03, 2950.69 and 3338.00keV γ-rays are confirmed again in the present work. One new level at 2027.72keV excitation energy is proposed. The level scheme was established and for a number of levels spin-parity assignments are suggested on the basis of logft values and γ-branching ratios.

Keywords: decay, γ-ray, level, coincidence
PACC: 2320L, 2320N, 2340, 2110H

1. Introduction

The decay of ^{72}As was previously studied by Camp[1] and Rester *et al.*[2] It should be pointed out that many γ-rays which belong to the decay of ^{72}As were not placed in the level scheme in their works. A literature survey shows that no recent experimental information concerns the decay scheme of this isotope. To be specific, the last published paper[2] widely cited is more than 30 years old. This serious inadequacy motivates the need for new, more accurate, measurements in this field. The results of our investigation of the ^{72}Ge isotope in radioactive decay are presented. In Section 2 the preparation of the ^{72}As source is presented. Sections 3 and 4 report on the results of singles and coincidence measurements and the model independent level scheme construction.

2. Source

The source of ^{72}As was produced through the ^{72}Ge(p, n)^{72}As reaction by irradiating natural germanium foil (purity of germanium element: 99.9999999%) with beam of 16MeV protons (I ≈0.7μA), obtained from the variable energy cyclotron (K=40) at the Shanghai Institute of Nuclear Research (SINR). There is a trace of element gallium in the target material. Small amounts of disturbing ^{71,74,76}As and ^{69}Ge activities, which are formed via (p, n) reactions, could be recognized by their half-lives. The measurement was started after a waiting period of ∼20h at the end of the irradiation and lasted about 300 seconds.

3. Experimental results

The γ-ray singles spectra have been studied using a Compton-suppressed coaxial low background spectrometer of 130cm^3 HpGe with 30% efficiency and its energy resolution is 1.9keV at FWHM for the 1332keV γ-ray of ^{60}Co, non-Compton-suppressed measurements are also carried out at the same time. The total background counts are 0.7cps (Compton-suppressed) and 1.3cps (non-Compton-suppressed) in the energy range of 36–2515keV. The low-energy region of the singles spectrum is shown in Fig.1(a), using a source–detector distance of 11cm. The γ-ray spectrum presented in Fig.1(b) shows the high-energy region recorded with an absorber composed of 0.6cm thick lead and 0.5cm thick cadmium to attenuate the low-energy radiations, and the source–detector distance is also 11cm. An upper case S or D in Fig.1 denotes single- or double-escape peaks, and Σ a sum

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peak. These spectra were analysed carefully with a computer program which fits each peak with adjustable lines shapes (approximately Gaussian). Then we calculate the peak area and centroid channel using the same computer program. The energy of strong peaks acted as calibration standards for weak peaks identified from the spectra. The energy and relative efficiency calibrations were performed with ^{152}Eu and ^{56}Co sources placed at the target position. The energies and relative intensities of γ-rays from the ^{72}As decay are summarized in Table 1. It should be pointed out that the uncertainties of the relative γ-ray intensities not only include the contributions from counting statistics, but also the uncertainties of the efficiency calibrations of the spectrometers and the normalization procedure are taken into account.

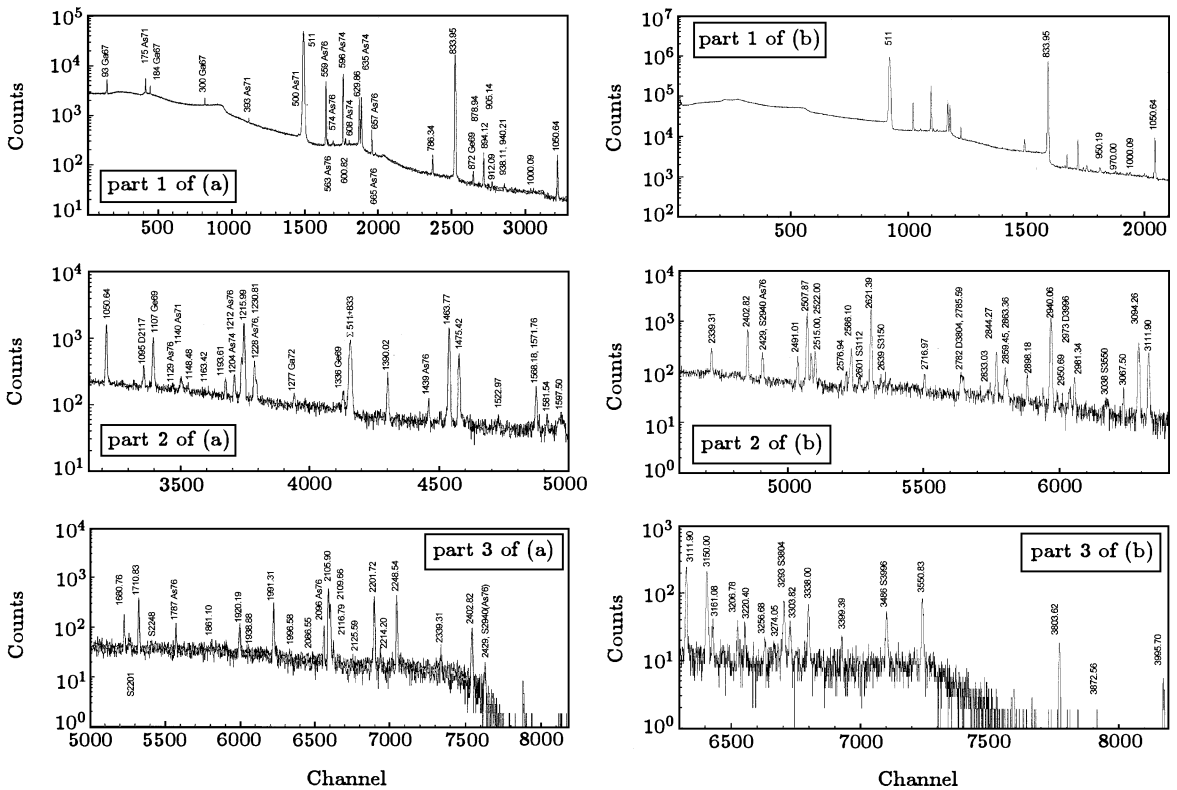


Fig.1. Gamma-single spectra of ^{72}Ge taken with an anti-Compton spectrometer. (a) The low-energy region part. (b) The high-energy region.

Table 1. The energies and relative intensities of γ-rays following the decay of ^{72}As.

This work				A. C. Rester *et al*[2]				D. C. Camp[1]			
Energy/keV[a]		I/%[a]		Energy/keV[a]		I%[a]		Energy/keV[a]		I%[a]	
113	0	–	–	113.1	2	0.036	4	112.5	5	0.030	5
142	0	–	–	142.5	2	0.010	4	142.5	1	0.022	3
428.21	12	0.077	14	428.5	2	0.083	8	428.4	2	0.094	10
479	0	–	–					479.6	3	0.028	2
600.82	7	0.518	18	600.93	5	0.040	2	600.9	1	0.394	12
629.86	6	10.30	33	629.93	5	10.2	3	629.9	1	9.860	200
691	0										
772.0	2	0.034	8					772.6	3	0.013	1
786.34	7	0.59	2	786.43	5	0.54	2	786.5	3	0.5867	19
833.95	6	100	3	834.00	3	100		833.95	5	100	
878.21	16	0.022	4	879.2	2	0.032	5	878.4	2	0.020	2
894.12	6	0.98	3	894.27	5	0.99	3	894.2	1	0.960	32
905.14	21	0.038	4	905.3	2	0.049	5	904.9	4	0.033	3

Table 1. (*Continued*)

This work				A. C. Rester *et al*[2]				D. C. Camp[1]			
Energy/keV[a]		I/%[a]		Energy/keV[a]		I%[a]		Energy/keV[a]		I%[a]	
912.09[f]	12	0.086	8	911.8	2	0.070	9	912.1	3	0.079	7
938	12	–	–	938.8	2	0.10	1	938.4	2	0.062	5
938.11	6	0.066	5					939.4	2	0.008	1
940.21	9	0.036	4	942	1	0.020	4	940.6	3	0.027	2
950.19	17	0.012	7					950.2	4	0.007	4
970.00	14	0.034	7					970.6	2	0.022	3
1000.09	21	0.031	8	999.84	8	0.037	5	999.9	2	0.029	3
1029.05	15	0.021	7	1031	1	0.035	7	1029.1	3	0.031	2
1050.64	6	1.22	4	1050.76	5	1.23	4	1050.7	1	1.243	34
1148.48	22	0.013	4					1148.4	3	0.015	4
1163.42	19	0.014	4					1163.1	2	0.017	2
1193.61[g]	9	0.105	7	1193.9	1	0.12	1	1193.4	3	0.105	3
1215.99[e]	6	0.19	6	1215.14	5	0.29	2	1215.1	2	0.259	7
1230.81	9	0.108	5	1230.8	1	0.099	7	1230.9	2	0.081	6
1276.65	13	0.049	7	1276.8	2	0.046	5	1276.8	2	0.053	5
1390.02	7	0.31	1	1390.44	5	0.30	1	1390.4	2	0.296	8
1463.77	6	1.38	18	1464.00	7	1.43	5	1464.0	1	1.381	28
1475.42	7	0.68	2	1475.91	7	0.63	2	1475.8	2	0.642	18
1522.97	15	0.024	5	1523	1	0.014	3	1522.5	7	0.024	6
1568.18	9	0.173	8	1568.2	1	0.18	1	1568.2	1	0.161	5
1571.76	17	0.025	2					1571.7	2	0.024	2
1581.54	11	0.035	6	1581.3	3	0.051	6	1581.2	3	0.029	2
1597.50	14	0.060	9					1596.8	2	0.030	2
1680.76	9	0.159	21	1680.7	1	0.15	1	1680.8	2	0.146	4
1710.83	9	0.332	43	1710.90	7	0.34	2	1710.9	2	0.305	10
1861.10	13	0.032	6					1861.1	1	0.025	2
1920.19	9	0.114	15	1921	1	0.06	2	1920.2	2	0.118	3
1938.88[c]	21	0.011	4					1939.0	4	0.010	1
1991.31	9	0.475	62	1991.14	8	0.48	2	1991.3	3	0.423	13
1996.58[bd]	15	0.044	6								
2086.55	16	0.028	5					20.86.4	3	0.018	1
2105.90	9	0.83	11	2105.9	3	0.93	9	2105.9	2	0.791	21
2109.66	9	0.49	6	2109.8	3	0.28	3	2109.5	2	0.339	9
21116.79[c]	11	0.044	6	2116.7	4	0.041	6	2116.5	3	0.035	2
2125.59[bd]	24	0.019	5								
2201.72	9	0.63	8	2201.74	9	0.65	2	2201.6	2	0.584	16
2214.20	11	0.036	6	2214.1	2	0.043	6	2214.3	3	0.037	3
2248.54	9	0.43	6	2248.5	1	0.42	2	2248.5	3	0.038	13
2255.49[b]	14	0.016	3								
2339.31	10	0.057	8	2339.8	2	0.043	5	2339.4	4	0.047	3
2402.82	9	0.16	2	2402.9	1	0.14	1	2402.2	4	0.020	1
								2402.5	3	0.125	4
2491.01	11	0.045	6	2491.0	2	0.041	6	2491.0	2	0.036	2
2507.87	9	0.44	6	2507.9	1	0.42	2	2507.7	2	0.402	11
2515.00	10	0.049	7	2515.4	2	0.029	5	2514.6	4	0.044	3
2522.00	10	0.068	9	2521.8	2	0.059	5	2521.9	3	0.058	4
2576.94	15	0.018	3					2577.6	8	0.023	3
2586.10	9	0.050	7	2585.0	3	0.12	1	2585.7	4	0.075	9
2621.39	9	0.54	7	2621.5	1	0.49	2	2621.1	3	0.484	13

Table 1. (*Continued*)

This work				A. C. Rester *et al*[2]				D. C. Camp[1]			
Energy/keV[a]		I/%[a]		Energy/keV[a]		I%[a]		Energy/keV[a]		I%[a]	
2716.97	15	0.017	3					2716.7	4	0.015	3
2785.59[c]	18	0.015	2					2785.1	5	0.018	2
2833.03[c]	24	0.008	2					2833.2	6	0.011	2
2844.27	9	0.08	1	2844.2	4	0.087	6	2843.9	2	0.066	4
2859.45	12	0.026	4	2860	1	0.04	1	2859.9	7	0.023	3
2863.36[d]	18	0.012	2	2864	1	0.02	1	2863.6	8	0.007	2
2898.18[d]	12	0.027	4	2898.6	4	0.035	5	2897.1	8	0.024	3
2940.06	9	0.41	5	2940.1	1	0.42	2	2939.6	4	0.362	10
2950.69[c]	27	0.006	1					2950.0	5	0.006	1
2981.34	12	0.025	4	2982.1	2	0.24	3	2981.0	3	0.016	3
3067.50[d]	15	0.010	2					3067.0	6	0.007	1
3094.26	9	0.14	2	3094.3	2	0.18	1	3093.7	3	0.121	5
3111.90	9	0.08	1	3112.4	3	0.10	1	3111.4	4	0.073	6
3150.00	9	0.08	1	3150.0	3	0.10	1	3149.7	4	0.075	7
3161.08	17	0.010	2	3161	1	0.010	3	3161.3	5	0.010	1
3206.78	15	0.012	2					3206.7	5	0.008	1
3220.40[d]	17	0.008	2					3220.5	5	0.009	2
3256.68	21	0.006	1					3256.0	8	0.003	5
3274.07[d]	25	0.005	1					3275.1	8	0.005	1
3303.82	20	0.011	2					3304.5	8	0.009	2
3338.00[c]	12	0.021	3	3337.7	4	0.028	4	3338.0	4	0.018	2
3399.39	24	0.007	2	3398	1	0.008	4	3399.1	7	0.004	6
3550.83	11	0.034	5	3550.4	8	0.031	5	3550.4	6	0.025	2
3803.62	17	0.14	2	3803.6	3	0.11	2	3803.2	3	0.128	7
3872.56	19	0.06	1	3872.0	5	0.006	2	3872.2	6	0.007	15
3995.70	32	0.05	1	3995.0	3	0.08	2	3995.0	5	0.062	4

[a] The reported uncertainties refer to the last significant digits.

[b] New γ-transition identified in the present work.

[c] The placement of γ-transition is confirmed in the present work again.

[d] γ-transition not placed in the decay scheme

[e] The energy and relative intensity of γ-ray are deduced from the coincidence spectrum.

[f] ^{72}Ge transition not assigned to the level scheme before, but placed into the decay scheme now.

[g] The placement of γ-transition is changed in the present work.

Coincidence measurements were made using two high-purity Ge detectors oriented at 90°, one of which was a planar Ge detector (GMX-20190) with 20% efficiency and 1.85 keV resolution at 1332keV and placed 10cm from the target, the other was a coaxial Ge detector (GEM-50195) with 50% efficiency and 2.0keV resolution at 1332keV and placed 15cm from the target. The data were stored in an event-by-event recording mode on a computer hard disk. For each event one time and two energy parameters of 8192 channels were included. The fast–slow coincidence circuit had a time resolution of about 20ns when gated by the ^{60}Co full energy peaks. For low-energy transitions it can be much larger. About 1.1×10^7 events were stored. The reconstruction of coincidence spectra was performed off-line. For each gate, a gross spectrum without random coincidence and background correction and a background spectrum were obtained. Coincidence relationships were determined by comparing this pair of spectra. Almost all transitions determined in singles spectra were observed in coincidence spectra too. On the other hand, several weak peaks which could not be separated in singles spectra were also identified in coincidence spectra. Selected results for some examples of coincidence spectra are shown in Fig.2.

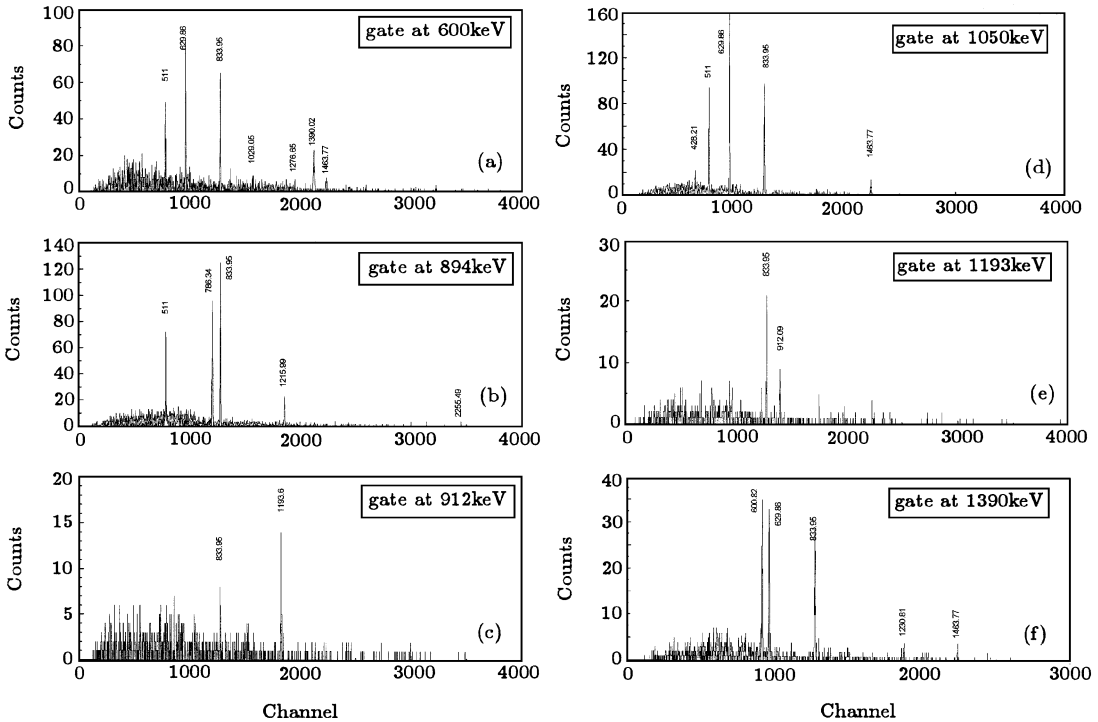
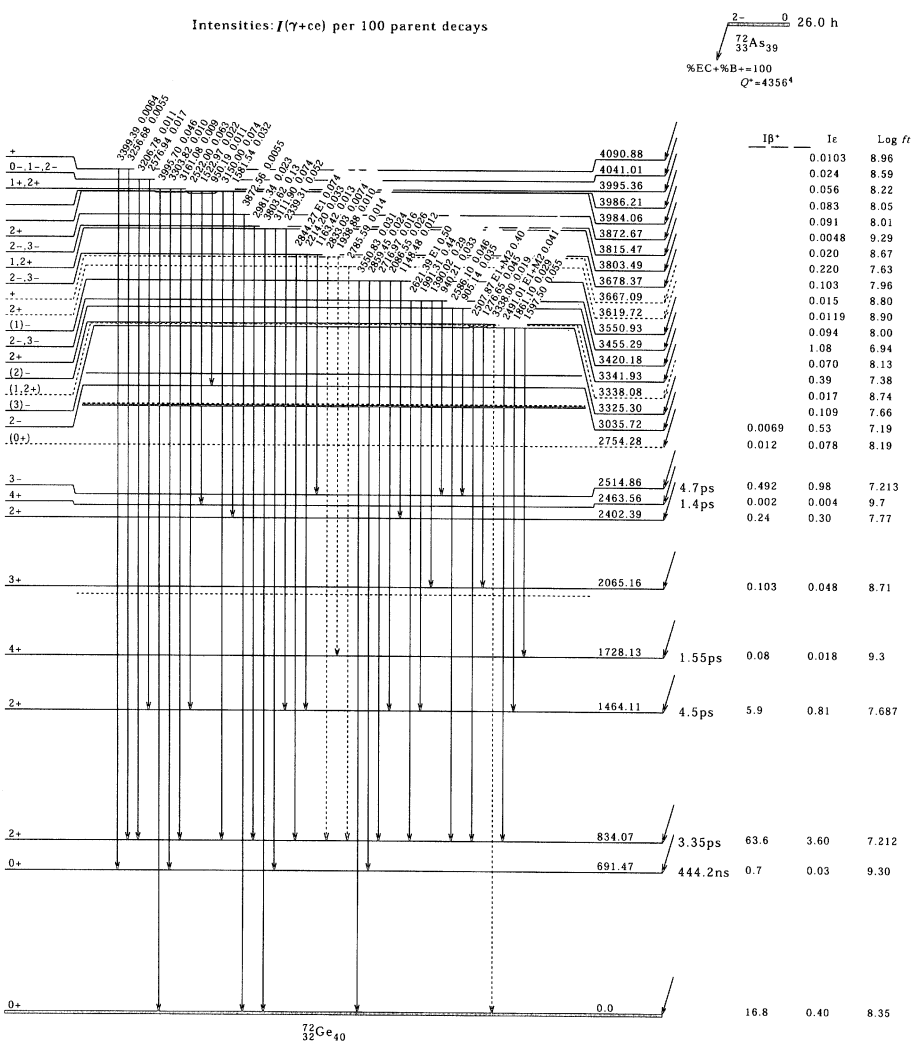


Fig.2. Some examples of coincidence spectra gated on (a) 600keV, (b) 894keV, (c) 912keV, (d) 1050keV, (e) 1193keV, (f) 1390keV γ-rays following the decay of ^{72}As, respectively.



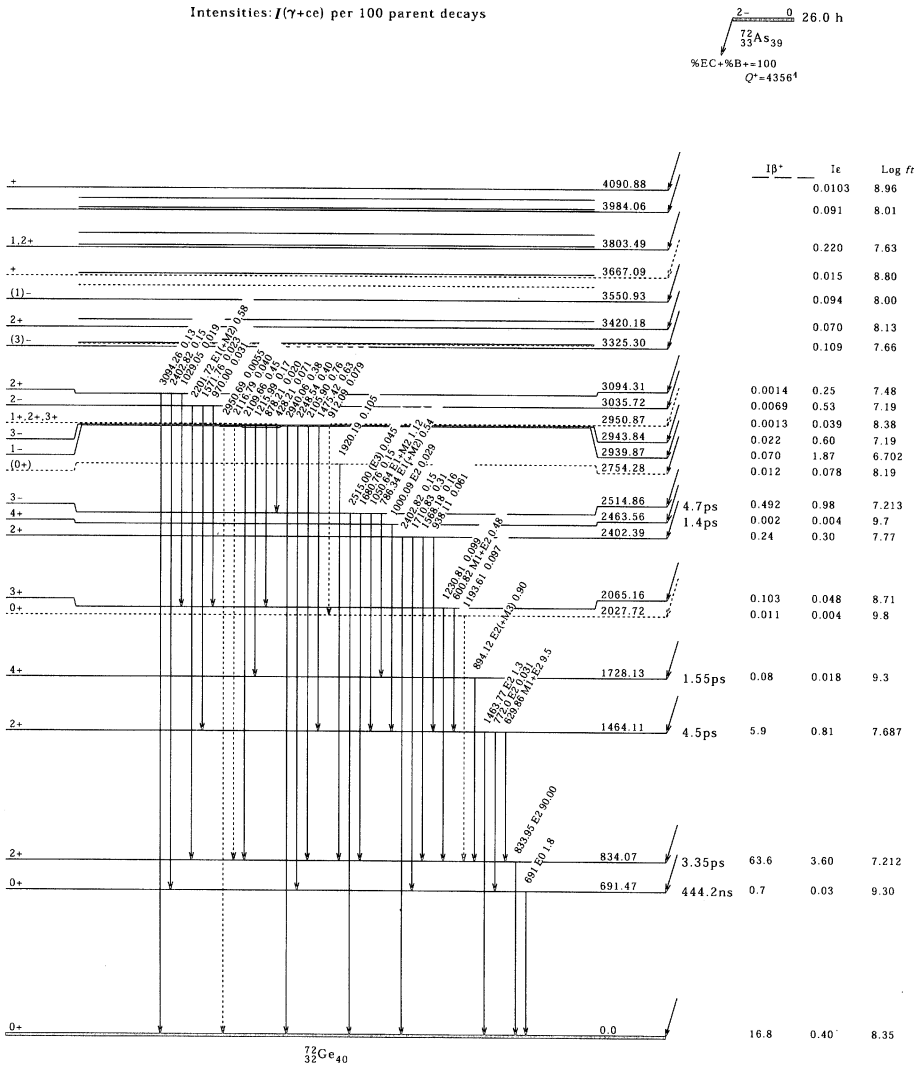


Fig.3. Decay scheme of ^{72}As proposed in this paper.

The present investigation of the ^{72}As decay provides an extension of the information concerning this decay. Approximately 79 transitions including 3 new transitions and 1 new level were assigned to ^{72}As, based on the measured half-life and/or observation in coincidence with well-known transitions. A decay scheme, which is shown in Fig.3, has been constructed consisting of 33 excited states and 77 transitions in ^{72}Ge. Additional new information has been obtained on γ-ray branching ratios, log(ft) values, spins and parities. The transitions and levels indicated by dotted lines denote the present experimental results which have some new contents.

4. Discussion of the decay scheme

The relative I (γ+ce) intensities were normalized to give 100 for the total feeding of the ground state, thus including a direct feeding of the ground state. The intensity of the 691.2keV internal conversion line is taken from Ref.[2]. The multipolarities and internal-conversion coefficients of transitions and the intensity of the direct (β^++EC) feeding of the ground state have also been taken from evaluated nuclear data.[3] From the γ-ray and internal-conversion electron intensities, the intensities of the direct (β^++EC) feeding of the levels were deduced by balancing the populating and depopulating intensity of each level. Finally, the logft values and the intensities of the β^+ and electron-capture branches to the ^{72}Ge levels were calculated by using the ENSDF (Evaluated Nuclear Structure Data File) analysis and checking program offered by NNDC (National Nuclear Data Centre) at Brookhaven National Laboratory. The result is presented in the decay scheme (Fig.3). The β^+(EC)-decay intensities are absolute and the $I_{\gamma+ce}$ are relative in Fig.3.

The establishment of the new 2027.72 level is based on the observation of the 912.09-1193.61-833.95 cascade. On the other hand, the 2029(3)keV level has been reported in the ^{70}Ge(t, p) reaction,[4,5] and its spin and parity are assigned as 0+. They are tentatively assigned as identical levels in the present work. The γ-rays at 1996.58, 2125.59 and 2255.49keV are observed in the present work for the first time, and their relative intensities are given in Table 1. The placement of 2255.49keV γ-ray has been assigned, but the other two have not.

In addition, one γ-ray at 912.09keV has been reported in Ref.[1] and Ref.[2], and not placed in the decay scheme before. In the present work, the placement of this γ-ray have been assigned for the first time. The γ-rays at 2863.36, 2898.18, 3067.50, 3220.40 and 3274.07 keV were also observed in the present work, and their relative intensities were given in Table 1, but their placements were not assigned yet. Six γ-rays with 1938.88, 2116.79, 2785.59, 2833.03, 2950.69 and 3338.00keV were tentatively placed in the previous decay scheme,[6] now the placements of these γ-rays are confirmed in the present work again. The γ-rays at 113, 142, 479 and 938 keV have been reported in Ref.[1] and/or Ref.[2], but they can't be observed in both singles spectra and coincidence spectra in the present work. Finally, the placement of 1193.61 keV γ-ray has been changed.

Acknowledgements

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