^{73}Se – Comments on evaluation of decay data by A. L. Nichols

Evaluated: October/November 2013 and March 2014

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) and other analytical techniques were applied to obtain averaged data throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the *values* used to calculate the average.

Decay Scheme

^{73}Se ($T_{½}$ = 7.10 h) decays 100 % by electron capture/β^+ decay (Q(EC) = 2725 (7) keV) to various excited nuclear levels and the ground state of ^{73}As. A reasonably well-defined decay scheme was derived from the gamma-ray measurements of 1969Ma21, 1970Me20 (1970MeZZ) and 1980Te01(1978TeZY), consisting of 16 EC/6 β^+ transitions and 53 gamma-ray emissions. Eighteen gamma-ray emissions were originally unplaced in the decay scheme, but only seven of these transitions have been successfully incorporated into the proposed decay scheme during the course of the current study. Weighted mean relative emission probabilities were calculated for the main gamma rays, while equivalent data for the other gamma transitions were adopted primarily from the more comprehensive measurements of 1980Te01. All of these relative emission probabilities have been defined in terms of the 360.866-keV gamma ray (100 %).

Nuclear Data

^{73}Se decay is viewed as a potentially suitable β^+ emitter for application in positron emission tomography (PET).

Half-life of ^{73}Se

The measurements of 1957Be46, 1960Ri09, 1967Ra08, 1969Ma21 and 1976Bo19 were adopted to give a weighted mean half-life of 7.10 (9) hours based on the limitation of relative statistical weight method (LWM).

Reference	Half-life (h)
1948Co07	7.1*
1951Sc70	7.1*
1957Be46	7.1 (3)
1960Ri09	7.1 (2)
1967Ra08	7.0 (1)
1969Ma21	7.18 (9)
1976Bo19	7.08 (15)
Recommended value	**7.10 (9)**§

* Uncertainty not specified – not included in weighted mean analysis of the data set.
§ Recommended uncertainty has been adjusted from 0.06 to 0.09, in alignment with the smallest uncertainty of the values used to calculate the average value.

Limitation of relative statistical weight method (LWM), normalised residual method (NRM), Rajeval technique, bootstrap method, and Mandel-Paule approach were considered in the analysis of the data set.

Analytical method	Half-life (h)	χ^2/(N-1)	$\chi^2/(N-1)_{critical}$
LWM	7.10 (6)*	0.45	3.32
NRM	7.10 (6)*	0.45	2.37
Rajeval	7.10 (6)*	0.45	−
Bootstrap	7.09 (3)	0.45	−
Mandel-Paule	null result	−	−

* Uncertainty increased from 0.06 to 0.09, in alignment with the smallest measured uncertainty of the values used to calculate the average value.

A half-life value of 7.10 (9) hours is recommended, as quantified by the LWM analytical procedure.

Half-life of daughter ^{73}As ground state

A half-life value of 80.30 (6) days for the ground state of daughter ^{73}As was adopted from 2004Si08.

Q-value

Q_{EC}-value for ^{73}Se EC/β^+ decay of 2725 (7) keV was adopted from Wang *et al.* (2012Wa38).

Gamma-ray energies and emission probabilities

Energies

The well-defined nuclear level energies of 2004Si08 were used to calculate the gamma transition energies and their uncertainties, and these data were adjusted to account for gamma recoil in the formulation of recommended gamma-ray emission energies and uncertainties. Greater confidence was placed on this overall method of assignment because of the more wide-ranging origins of the gamma transition data in 2004Si08, even though the energies of a significant number of gamma-ray emissions have been directly measured by 1969Ma21, 1970Me20 and 1980Te01. The 1961.8-, 2434.1- and 2476.1-keV levels are notable exceptions to this approach – the energies of these particular nuclear levels of ^{73}As were determined from the energies of observed gamma rays that possess the potential to populate already known nuclear levels after depopulating proposed nuclear levels that can be closely identified with the energies of other particular levels listed by 2004Si08. Short-lived half-lives for the 67.039- and 427.906-keV nuclear levels were adopted from weighted-mean analyses of the measurements of 1956Ha10, 1963Bo16, 1963Bo26, 1966Ol04, 1969Iv02, 1969Ma21, 1972ReZN and 1977KeZY.

Adopted energies, spins and parities for the nuclear levels of ^{73}As (2004Si08).

Nuclear level number	Nuclear level energy (keV)	Spin and parity	Half-life
0	0.0	3/2 −	80.30 (6) d ^{73}As
1	67.039 (8)	5/2 −	4.97 (7) ns
2	427.906 (21)	9/2 +	5.75 (20) μs
3	510.055 (17)	(5/2) +	
4	993.766 (12)	(7/2) −	
5	1037.13 (3)	(13/2) +	
6	1178.052 (21)	(7/2) −	
7	1275.14 (7)	(7/2) +	
8	1293.09 (10)	(11/2) +	
9	1293.37 (3)	(7/2) +	
10	1328.89 (5)	(7/2, 9/2) +	
11	1850.59 (5)	(9/2) +	
12	1910.13 (12)	(9/2 +, 11/2)	
13	1961.8 (2)*	(3/2, 5/2, 7/2)	
14	1975.41 (11)	(7/2, 9/2, 11/2 +)	
15	2180.66 (10)	(7/2, 9/2 +)	
16	2311.63 (6)	(7/2, 9/2 +)	
17	2434.1 (4)#	3/2+, 5/2+	
18	2476.1 (2)†	(11/2, 15/2)	
19	2482.87 (23)	(7/2, 9/2 +)	
20	2584.09 (11)	(7/2, 9/2 −)	

* Energy of nuclear level derived from observed 1451.7-keV gamma-ray depopulation, with spin assigned originally by 2004Si08 for a 1962.23 (17)-keV nuclear level.

\# Energy of nuclear level derived from observed 2006.2-keV gamma-ray depopulation, with spin and parity assigned originally by 2004Si08 for a 2436 (10)-keV nuclear level.

† Energy of nuclear level derived from observed 1439.0- and 2048.2-keV gamma-ray depopulation, with spin assigned originally by 2004Si08 for a 2475.49 (20)-keV nuclear level.

Half-life measurements and recommended values of the 67.039- and 427.906-keV nuclear levels of ^{73}As.

Level (keV)	Half-life								
	1956Ha10	1963Bo16	1963Bo26	1966Ol04	1969Iv02	1969Ma21	1972ReZN	1977KeZY	Recommended#
67.039 (ns)	< 5	6.1 (4)	5.0 (1)	4.95 (7)	−	−	−	−	4.97 (7) ns
427.906 (μs)	6.0 (2)	5.0 (4)	−	−	6 (1)	5.6 (3)	5.8 (2)	5.66 (23)	5.75 (20) μs

\# Data analysis based on limitation of relative statistical weight method (LWM), normalised residual method (NRM), Rajeval technique, and bootstrap method.

Gamma transition energies, and measured and recommended gamma-ray energies.

E_{TP} (keV)[#]	E_γ (keV)					
	1960Ri09	1967Ra08	1969Ma21	1970Me20	1980Te01	Recommended[§]
67.039 (8)	65 (2)	66.9(5)	67.0 (1)	67.0 (1)	67.07 (10)	67.039 (8)
360.867 (23)	360 (5)	360.4 (5)	361.1 (1)	360.9 (1)	361.2 (3)	360.866 (23)
427.906 (21)	–	–	–	–	428.3 (3)	427.905 (21)
443.016 (19)	–	–	443(1)	442.5 (8)	442.3 (3)	443.015 (19)
510.055 (17)	–	–	–	509.5 (8)	509.4	510.053 (17)
–	–	–	511.0	511.0	511.0	annihilation radiation
557.50 (11)	–	–	556.9 (8)	–	557.9 (5)	557.50 (11)
575.45 (9)	–	–	–	–	575.9 (5)	575.45 (9)
600.3 (3)[Δ]	–	–	–	–	600.33 (29)	600.3 (3)[Δ]
609.22 (4)	–	–	–	–	609.17 (19)	609.22 (4)
682.04 (11)	–	–	683*	682.0 (8)	682.25 (20)	682.04 (11)
700.27 (13)	–	–	700.5 (8)	699.9 (10)	700.0 (5)	700.27 (13)
765.09 (7)	–	–	765.0 (9)	764.4 (8)	765.07 (12)	765.09 (7)
783.32 (4)	–	–	783.7 (7)	782.9 (8)	783.7 (3)	783.32 (4)
793.0 (5)[Δ]	–	–	–	–	793.0 (5)	793.0 (5)[Δ]
813.46 (6)	–	–	–	–	813.38 (29)	813.46 (6)
818.84 (5)	–	–	819.0 (3)	818.4 (8)	818.65 (15)	818.84 (5)
847.23 (7)	–	–	847.5 (5)	847.2 (8)	847.16 (17)	847.22 (7)
856.82 (5)[Φ]	–	–	–	–	857.0 (3)	856.81 (5)[Φ]
865.18 (10)[¶] {	–	–	865.4 (2)	864.9 (5)	865.09 (12)	} 865.17 (10)[¶]
865.46 (3)[¶] {						} 865.45 (3)[¶]
873.00 (12)	–	–	–	–	872.56 (27)	872.99 (12)
887.29 (10)	–	–	–	–	887.46 (18)	887.28 (10)
900.98 (5)	–	–	901.2 (4)	901.3 (5)	900.73 (10)	900.97 (5)
926.727 (14)	–	–	–	–	926.19 (15)	926.721 (14)
930.09 (15)[Δ]	–	–	–	–	930.09 (15)	930.09 (15)[Δ]
968.0 (2)[†]	–	–	969 (1)	968.1 (8)	968.1 (1)	968.0 (2)[†]
982.74 (8)	–	–	983.6 (4)	982.5 (8)	982.75 (13)	982.73 (8)
993.766 (12)	–	–	–	–	993.52 (12)	993.759 (12)
1002.61 (10)	–	–	–	–	1001.9 (2)	1002.60 (10)
1018.26 (7)	–	–	–	–	1018.52 (13)	1018.25 (7)
1036.49 (9)	–	–	–	–	1036.38 (9)	1036.48 (9)
1111.013 (23)	–	–	1111.0 (4)	1110.8 (5)	1110.64 (6)	1111.004 (23)
1153.98 (24)	–	–	–	–	1153.9 (3)	1153.97 (24)
1159.0 (4)[‡]	–	–	–	–	1158.2 (4)	1159.0 (4)[‡]
1208.10 (7)	–	–	–	–	1207.9 (3)	1208.09 (7)
1215.4 (8)[Δ]	–	–	–	1215.4 (8)	1215.4 (8)	1215.4 (8)[Δ]
1226.33 (3)	–	–	–	–	1226.6 (9)	1226.32 (3)
1249.9 (2)[Δ]	–	–	–	–	1249.9 (2)	1249.9 (2)[Δ]
1275.14 (7)	–	–	–	–	1274.39 (21)	1275.13 (7)
1308.95 (13)	–	–	–	–	1308.9 (2)	1308.94 (13)
1317.86 (6)	–	–	–	–	1317.75 (21)	1317.85 (6)
1323.81 (20)[Δ]	–	–	–	–	1323.81 (20)	1323.81 (20)[Δ]
1340.54 (5)	–	–	1341.0 (5)	1340.7 (8)	1340.50 (7)	1340.53 (5)
1406.04 (11)	–	–	–	–	1406.3 (4)	1406.03 (11)
1422.68 (6)	–	–	1422.9 (2)	1422.5 (5)	1422.68 (7)	1422.67 (6)
1439.0 (2)[▲]	–	–	–	–	1439.10 (17)	1439.0 (2)[▲]
1451.7 (2)[†]	–	–	–	–	1451.62 (2)[*]	1451.7 (2)[†]
1482.22 (6)	–	–	1480 (1)	1482.3 (10)	1482.29 (12)	1482.20 (6)
1547.50 (11)	–	–	1548.1 (6)	1548.0 (8)	1547.45 (12)	1547.48 (11)
1670.61 (10)	–	–	–	–	1670.81 (16)	1670.59 (10)
1738.4 (5)[Δ]	–	–	–	–	1738.4 (5)	1738.4 (5)[Δ]
1752.75 (10)	–	–	–	–	1752.88 (20)	1752.73 (10)
1801.58 (6)	–	–	–	–	1801.36 (14)	1801.56 (6)
1847.8 (3)[Δ]	–	–	–	–	1847.82 (26)	1847.8 (3)[Δ]
1883.72 (6)	–	–	–	–	1883.85 (15)	1883.69 (6)

1889.57 (20)$^{\Delta}$	–	–	–	–	1889.57 (20)	1889.57 (20)$^{\Delta}$
1972.82 (23)	–	–	–	–	1973.4 (4)	1972.79 (23)
2006.2 (4)‡	–	–	–	–	2006.2 (4)	2006.2 (4)‡
2023.9 (3)$^{\Delta}$	–	–	–	–	2023.86 (26)	2023.9 (3)$^{\Delta}$
2048.2 (2)$^{▲}$	–	–	–	–	2048.1 (8)	2048.2 (2)$^{▲}$
2054.96 (23)	–	–	–	–	2053.8 (6)	2054.93 (23)
2156.18 (11)	–	–	–	–	2156.04 (14)	2156.15 (11)
2170.5 (3)$^{\Delta}$	–	–	–	–	2170.50 (26)	2170.5 (3)$^{\Delta}$
2517.05 (11)	–	–	–	–	2517.31 (25)	2517.00 (11)

$^{\#}$ Determined from the nuclear level energies of 2004Si08.
§ Calculated by subtracting gamma recoil from gamma transition energy (E_{TP} (keV)).
$^{\Delta}$ Unplaced in proposed decay scheme.
¶ Unresolved doublet derived from proposed decay scheme.
* Reported uncertainty believed to be in error when compared with defined uncertainties of all other equivalent data – modified to 1451.62(20) keV.
$^{\Phi}$ Proposed gamma-ray depopulation of 1850.59-keV nuclear level of ^{73}As.
† Proposed gamma-ray depopulation of 1961.8-keV nuclear level of ^{73}As.
‡ Proposed gamma-ray depopulation of 2434.1-keV nuclear level of ^{73}As.
$^{▲}$ Proposed gamma-ray depopulation of 2476.1-keV nuclear level of ^{73}As.

Emission Probabilities

All of the relative emission probabilities were suitably refined and quantified in terms of the emission probability of the 360.866-keV gamma ray (100.0 %). Relative gamma-ray emission probabilities have been partially or fully determined in the measurements of 1960Ri09, 1967Ra08, 1969Ma21, 1970Me20 and 1980Te01, although much greater emphasis was placed on the studies of 1969Ma21, 1970Me20 and 1980Te01 when undertaking weighted-mean analyses of the appropriate and most significant relative emission probabilities. Considerably more detail can be found within the gamma-ray measurements of ten Brink *et al.* (1980Te01), and therefore the data of 1980Te01 were directly adopted for many of the low-intensity gamma-ray emissions in preference to any semi-artificial weighting procedure. Eighteen previously unplaced gamma-ray emissions were re-considered from the point of view of the known nuclear levels of ^{73}As and the possible observation of emissions from other radionuclides that might be generated during the various irradiations (i.e. Ga, Ge, As and other Se isotopes). A number of these gamma-ray emissions can be incorporated into the proposed decay scheme: 856.81, 968.0, 1159.0, 1439.0, 1451.7, 2006.2 and 2048.2 keV. Despite these efforts, eleven observed gamma rays remain unplaced in the proposed decay scheme, although they are contained within the recommended data set: 600.3, 793.0, 930.09, 1215.4, 1249.9, 1323.81, 1738.4, 1847.8, 1889.57, 2023.9 and 2170.5 keV.

Previously unplaced gamma transitions (2004Si08).

E_{γ} (keV)	P_{γ}^{rel}	Assignment	Comments
600.3 (3)	0.021 (3)	–	Only observed by 1980Te01. Possible to assign to 1178.06 → 577.90 and/or 993.78 → 393.43, but lack of evidence of depopulating 577.9-keV, and 393.4- and 309.1-keV γ-ray emissions, respectively, as specified by 1997So08.
793.0 (5)	0.066 (2)	–	Only observed by 1980Te01.
856.81 (5)	0.024 (6)	1850.59 → 993.766	Only observed by 1980Te01.
930.09 (15)	0.005 (1)	–	Only observed by 1980Te01.
968.0 (2)	0.012 (5)	1961.8 → 993.766	Observed by 1969Ma21, 1970Me20 and 1980Te01.
1159.0 (4)	0.003 (1)	2434.1 → 1275.14	Only observed by 1980Te01.
1215.4 (8)	0.065 (10)	–	Observed by 1970Me20 and 1980Te01.
1249.9 (2)	0.004 (1)	–	Only observed by 1980Te01.
1323.81 (20)	0.007 (1)	–	Only observed by 1980Te01.
1439.0 (2)	0.002 (1)	2476.1 → 1037.13	Only observed by 1980Te01.
1451.7 (2)	0.006 (2)	1961.8 → 510.055	Only observed by 1980Te01.
1738.4 (5)	0.002 (1)	–	Only observed by 1980Te01.
1847.8 (3)	0.008 (1)	–	Only observed by 1980Te01.
1889.57 (20)	0.003 (1)	–	Only observed by 1980Te01.
2006.2 (4)	0.002 (1)	2434.1 → 427.906	Only observed by 1980Te01.
2023.9 (3)	0.002 (1)	–	Only observed by 1980Te01.
2048.2 (2)	0.001 (1)	2476.1 → 427.906	Only observed by 1980Te01.
2170.5 (3)	0.002 (1)	–	Only observed by 1980Te01.

Extensive γ singles, γ-γ coincidence and conversion-electron spectral measurements by Sohler *et al.* (1997So08) of the prompt gamma-ray emission induced by the ^{73}Ge(p,nγ) reaction provided additional support towards defining the detailed structure of the ^{73}Se decay scheme.

Nine possible unresolved doublets have been proposed in the studies of 1997So08 that required further assessment to ensure their justifiable adoption or rejection:

317-keV doublet rejected – no 317-keV gamma rays observed in the ^{73}Se EC decay studies,
376-keV doublet rejected – no 376-keV gamma rays observed in the ^{73}Se EC decay studies,
484-keV doublet rejected – no 484-keV gamma rays observed in the ^{73}Se EC decay studies,
510-keV doublet – identified as the gamma-ray transition between the 510.055 → 0.0 keV nuclear levels in the 73Se decay scheme; other possibility of a gamma-ray transition between the 577.9 → 67.04 keV nuclear levels rejected because no 577.9-keV gamma emission was observed, although specified to be the major depopulating transition from a 577.9-keV nuclear level by 1997So08,
600-keV doublet – both gamma-ray transitions between the 1178.0 → 577.9 and 993.8 → 393.4 keV nuclear levels rejected because of a lack of evidence of any depopulating 577.9-keV, and 393.4- and 309.1-keV gamma-ray emissions, respectively, as specified by 1997So08,
643-keV doublet rejected − no 643-keV gamma rays observed in the 73Se EC decay studies,
724-keV doublet rejected − no 724-keV gamma rays observed in the 73Se EC decay studies,
865-keV doublet accommodated as the two gamma transitions between the 1293.37 → 427.906 and 1293.09 → 427.906 keV nuclear levels,
994-keV doublet − identified as the gamma-ray transition between the 993.8 → 0.0 keV nuclear levels in the 73Se decay scheme; other possibility of a gamma-ray transition between the 1077.8 → 84.3 keV nuclear levels rejected because there is no gamma-ray evidence for the existence of depopulating 1077.8- and 84.3-keV nuclear levels in ^{73}Se EC decay.

The undetermined relative emission probability of the 510.053-keV γ ray was calculated to be 0.27 (3) % from the relative emission probability ratio of the 510.053- and 443.015-keV γ rays depopulating the 510.055-keV nuclear level of ^{73}As, as determined by 1997So08 from their studies of the ^{73}Ge(p,nγ) reaction to be 214.1 (270) % and 41.1 (41) %, respectively. Another problem is posed by the 865-keV gamma-ray doublet which arises from the depopulation of both the 1293.37- and 1293.09-keV nuclear levels of ^{73}As, as detected in the γ-γ coincidence studies of the ^{73}Ge(p,nγ)^{73}As reaction by 1997So08. Gamma-ray spectroscopy studies of this region by 1969Ma21. 1970Me20 and 1980Te01 were only interpreted in terms of one 865-keV gamma transition and a single 1293-keV nuclear level, while 1997So08 undertook γ-γ coincidence measurements in which an 865-keV doublet of 865.17/865.45 keV was demonstrated to exist of unresolved structure. Problems arose in the evaluation when attempting to achieve a satisfactory population-depopulation balance for the 1293.37-keV level involving the 865.45-keV gamma ray and relative intensity determined by 1997So08, which also impacted inevitably on the 865.17-keV gamma-ray depopulation of the 1293.09-keV level. The relative emission probability of the 865.45-keV gamma ray was calculated to be 0.02 (1) % from the relative emission probability ratio of the 865.45- and 783.32-keV gamma rays depopulating the 1293.37-keV nuclear level of ^{73}As, as determined by 1997So08, while the relative emission probability of the 865.17-keV gamma ray depopulating the 1293.09-keV nuclear level of ^{73}As was defined as 0.540 (17) - 0.02 (1) = 0.52 (2) %.

Absolute total (EC + β^+) decay to the 67.039-keV was determined from the positron spectroscopy studies of 1951Sc70, 1956Ha10 and 1968Ak03. A weighted-mean value of 1.07 ± 0.20 was adopted for the relative $P_{\beta+}$ of the $\beta^+_{0,1}$ transition as derived from the positron emission measurements of 1951Sc70 and 1956Ha10 and 1968Ak03 with estimated uncertainties. The reasonably comprehensive gamma-ray spectroscopy studies of 1969Ma21, 1970Me20 and 1980Te01 support an extremely significant and dominant population of the 427.906-keV nuclear level of ^{73}As by direct EC/β^+ decay. An EC/β^+ ratio of 0.522 can be assigned to this allowed 2297-keV EC transition/1275-keV β^+ emission as determined from the tabulations of Gove and Martin (1971Go40). Both the equivalent relative P_{EC} and total $P_{(EC\,+\,\beta+)}$ were calculated on the basis of the dominance of the 2297-keV EC/β^+ transition. Furthermore, absolute total $P_{(EC\,+\,\beta+)}$ values of 98.8 (2) % and 1.2 (2) % can be determined for the $(EC_{0,2} + \beta^+_{0,2})$ plus all lowly-populated higher-energy levels, and $(EC_{0,1} + \beta^+_{0,1})$, respectively.

Measured and calculated positron emission and EC transition probabilities (1951Sc70, 1956Ha10, 1968Ak03).

$E_{\beta+}$ (keV)	Relative $P_{\beta+}$				ε/β (theory)	Relative P_{EC}	Relative total $P_{(EC+\beta+)}$	Absolute total $P_{(EC+\beta+)}$ (%)
	1951Sc70	1956Ha10	1968Ak03[#]	Recommended relative $P_{\beta+}$	1971Go40			
250 ?	1.3	–	–	)		)	)	)
750 ?	11.8	–	8 → 8.8	) 100	0.522	) 52.2	) 152.2	) 98.8 (2)
1275 $\beta^+_{0,2}$	100	100	91.3 → 100	)		)	)	)
1636 $\beta^+_{0,1}$	1.4 → 1.4 (2)	~ 1 → 1.0 (2)	0.7 → 0.8 (2)	1.07 (20)	0.741	0.79	1.86 → 1.9 (2)	1.2 (2)
			∑ 100				∑ 154.1 ≡ 100	∑ 100

[#] Described as the intensities of partial β+ transitions.

A normalisation factor for the relative gamma-ray emission and EC/β$^+$ transition probabilities was calculated by assigning a value of 100 % to the total gamma and EC/β$^+$ transition probabilities directly populating the 67.039- and 0.0-keV nuclear levels of ^{73}As, assuming zero EC/β$^+$ decay directly to the ground state based on spin-parity considerations (9/2+ → 3/2− constitutes a third forbidden non-unique transition (3, yes)):

$$\sum_{67.039\ keV}^{\gamma\ population} TP_\gamma \quad + \quad \sum_{0.0 keV}^{\gamma\ population} TP_\gamma \quad + \quad \sum (P_{EC_{0,1}} + P_{\beta^+_{0,1}}) \quad = \quad 100$$

and excluding the 67.039-keV gamma transition between the two nuclear levels. Thus:

$$101.590\ (20)\ F \quad + \quad 0.363\ (34)\ F \quad + \quad 1.2\ (2) \qquad = \qquad 100$$

where F is the normalisation factor for the relative gamma-ray emission and EC/β$^+$ transition probabilities.

$$F \quad = \quad 98.8\ (2)\ /\ 101.953\ (39)$$

$$F \quad = \quad 0.9691 \pm 0.0020$$

Measured and recommended gamma-ray emission probabilities relative to P_γ(360.866 keV) of 100 %.

E_γ (keV)		P^{rel}_γ						
		1960Ri09[#]	1967Ra08	1969Ma21	1970Me20	1980Te01	Recommended[*]	
$\gamma_{1,0}$	67.039 (8)	105 (10) → 66 (9)	76 (8)	**73 (7)**	**73.0 (74)**	**72 (8)**	73 (7) ↔ 81 (8)[+]	
$\gamma_{2,1}$	360.866 (23)	160 (15) → 100	100	100	100	100	100	
$\gamma_{2,0}$	427.905 (21)	–	–	–	–	0.080 (15)	0.080 (15)	
$\gamma_{3,1}$	443.015 (19)	–	–	**0.04 (1)**	**0.06 (1)**	**0.052 (3)**	0.052 (3)	
$\gamma_{3,0}$	510.053 (17)	–	–	–	–	–	0.27 (3)[§]	
$\gamma^\pm$	511	200 → **125 (12)**	–	**126 (3)**	**128 (13)**	–	126 (3) → 133 (8)[θ] annihilation radiation	
$\gamma_{11,8}$	557.50 (11)	–	–	**0.04 (1)**	–	**0.055 (2)**	0.054 (2)	
$\gamma_{11,7}$	575.45 (9)	–	–	–	–	0.150 (7)	0.150 (7)	
$\gamma_{-1,1}$	600.3 (3)[Δ]	–	–	–	–	0.021 (3)	0.021 (3)	
$\gamma_{5,2}$	609.22 (4)	–	–	–	–	0.051 (4)	0.051 (4)	
$\gamma_{14,9}$	682.04 (11)	–	–	**0.02 (1)**	0.09 (4)	**0.020 (2)**	0.020 (2)	
$\gamma_{14,7}$	700.27 (13)	–	–	**0.03 (1)**	**0.04 (1)**	**0.046 (2)**	0.045 (2)	
$\gamma_{7,3}$	765.09 (7)	–	–	**0.10 (3)**	**0.14 (2)**	**0.131 (2)**	0.131 (2)	
$\gamma_{9,3}$	783.32 (4)	–	–	**0.06 (2)**	**0.06 (2)**	**0.060 (2)**	0.060 (2)	
$\gamma_{-1,2}$	793.0 (5)[Δ]	–	–	–	–	0.066 (2)	0.066 (2)	
$\gamma_{11,5}$	813.46 (6)	–	–	–	–	0.009 (1)	0.009 (1)	
$\gamma_{10,3}$	818.84 (5)	–	–	**0.02 (1)**	**0.04 (2)**	**0.038 (2)**	0.037 (2)	
$\gamma_{7,2}$	847.22 (7)	–	–	**0.06 (2)**	**0.08 (1)**	**0.083 (6)**	0.081 (6)	
$\gamma_{11,4}$	856.81 (5)[Φ]	–	–	–	–	0.024 (6)	0.024 (6)	
$\gamma_{8,2}$	865.17 (10)[¶]	–	–	} 0.49 (3)	} **0.55 (6)**	} **0.540 (17)**	} 0.540 (17)	0.52 (2)[$]
$\gamma_{9,2}$	865.45 (3)[¶]			}	}	}	}	0.02 (1)[$]
$\gamma_{12,5}$	872.99 (12)	–	–	–	–	0.039 (7)	0.039 (7)	
$\gamma_{15,9}$	887.28 (10)	–	–	–	–	0.011 (8)	0.011 (8)	
$\gamma_{10,2}$	900.97 (5)	–	–	**0.12 (3)**	**0.15 (2)**	**0.139 (2)**	0.139 (2)	
$\gamma_{4,1}$	926.721 (14)	–	–	–	–	0.004 (1)	0.004 (1)	
$\gamma_{-1,3}$	930.09 (15)[Δ]	–	–	–	–	0.005 (1)	0.005 (1)	
$\gamma_{13,4}$	968.0 (2)[†]	–	–	**0.010 (5)**	**0.02 (1)**	–	0.012 (5)	

$\gamma_{16,10}$ 982.73 (8)	−	−	**0.02 (1)**	**0.03 (1)**	**0.035 (1)**	0.035 (1)
$\gamma_{4,0}$ 993.759 (12)	−	−	−	−	0.005 (1)	0.005 (1)
$\gamma_{15,6}$ 1002.60 (10)	−	−	−	−	0.004 (1)	0.004 (1)
$\gamma_{16,9}$ 1018.25 (7)	−	−	−	−	0.055 (2)	0.055 (2)
$\gamma_{16,7}$ 1036.48 (9)	−	−	−	−	0.015 (1)	0.015 (1)
$\gamma_{6,1}$ 1111.004 (23)	−	−	**0.18 (5)**	**0.19 (2)**	**0.207 (2)**	0.207 (2)
$\gamma_{19,10}$ 1153.97 (24)	−	−	−	−	0.005 (1)	0.005 (1)
$\gamma_{17,7}$ 1159.0 (4)‡	−	−	−	−	0.003 (1)	0.003 (1)
$\gamma_{7,1}$ 1208.09 (7)	−	−	−	−	0.004 (1)	0.004 (1)
$\gamma_{-1,4}$ 1215.4 (8)$^{\Delta}$	−	−	**0.07 (1)**	**0.06 (1)**	−	0.065 (10)
$\gamma_{9,1}$ 1226.32 (3)	−	−	−	−	0.003 (2)	0.003 (2)
$\gamma_{-1,5}$ 1249.9 (2)$^{\Delta}$	−	−	−	−	0.004 (1)	0.004 (1)
$\gamma_{7,0}$ 1275.13 (7)	−	−	−	−	0.007 (1)	0.007 (1)
$\gamma_{20,7}$ 1308.94 (13)	−	−	−	−	0.004 (1)	0.004 (1)
$\gamma_{16,4}$ 1317.85 (6)	−	−	−	−	0.006 (1)	0.006 (1)
$\gamma_{-1,6}$ 1323.81 (20)$^{\Delta}$	−	−	−	−	0.007 (1)	0.007 (1)
$\gamma_{11,3}$ 1340.53 (5)	−	−	−	**0.09 (2)**	**0.071 (2)**	0.071 (2)
$\gamma_{20,6}$ 1406.03 (11)	−	−	−	−	0.002 (1)	0.002 (1)
$\gamma_{11,2}$ 1422.67 (6)	−	−	**0.11 (3)**	**0.14 (2)**	**0.140 (5)**	0.139 (5)
$\gamma_{18,5}$ 1439.0 (2)▲	−	−	−	−	0.002 (1)	0.002 (1)
$\gamma_{13,3}$ 1451.7 (2)†	−	−	−	−	0.006 (2)	0.006 (2)
$\gamma_{12,2}$ 1482.20 (6)	−	−	0.008 (5)	**0.03 (1)**	**0.023 (1)**	0.023 (1)
$\gamma_{14,2}$ 1547.48 (11)	−	−	**0.03 (1)**	**0.04 (1)**	**0.032 (1)**	0.032 (1)
$\gamma_{15,3}$ 1670.59 (10)	−	−	−	−	0.005 (1)	0.005 (1)
$\gamma_{-1,7}$ 1738.4 (5)$^{\Delta}$	−	−	−	−	0.002 (1)	0.002 (1)
$\gamma_{15,2}$ 1752.73 (10)	−	−	−	−	0.011 (1)	0.011 (1)
$\gamma_{16,3}$ 1801.56 (6)	−	−	−	−	0.020 (5)	0.020 (5)
$\gamma_{-1,8}$ 1847.8 (3)$^{\Delta}$	−	−	−	−	0.008 (1)	0.008 (1)
$\gamma_{16,2}$ 1883.69 (6)	−	−	−	−	0.031 (2)	0.031 (2)
$\gamma_{-1,9}$ 1889.57 (20)$^{\Delta}$	−	−	−	−	0.003 (1)	0.003 (1)
$\gamma_{19,3}$ 1972.79 (23)	−	−	−	−	0.001 (1)	0.001 (1)
$\gamma_{17,2}$ 2006.2 (4)‡	−	−	−	−	0.002 (1)	0.002 (1)
$\gamma_{-1,10}$ 2023.9 (3)$^{\Delta}$	−	−	−	−	0.002 (1)	0.002 (1)
$\gamma_{18,2}$ 2048.2 (2)▲	−	−	−	−	0.001 (1)	0.001 (1)
$\gamma_{19,2}$ 2054.93 (23)	−	−	−	−	0.003 (1)	0.003 (1)
$\gamma_{20,2}$ 2156.15 (11)	−	−	−	−	0.005 (1)	0.005 (1)
$\gamma_{-1,11}$ 2170.5 (3)$^{\Delta}$	−	−	−	−	0.002 (1)	0.002 (1)
$\gamma_{20,1}$ 2517.00 (11)	−	−	−	−	0.005 (1)	0.005 (1)

Emission probabilities expressed relative to P_γ for 511-keV annihilation radiation of 200 %.

* Emission probabilities expressed relative to P_γ(360.866 keV) of 100 %.

+ Weighted-mean relative emission probability can be either adjusted in an arbitrary manner from 73 (7) % to 81 (8) % if assigned mulitipolarity of 100 % M1, or modified to (M1 + 4.3 % E2) multipolarity to maintain relative emission probability of 73 (7) % to ensure satisfactory depopulation of the 67.039-keV nuclear level to the ground state of ^{73}As.

§ Calculated from relative emission probability ratio of 510.053- and 443.015-keV γ rays depopulating the 510.055-keV nuclear level of ^{73}As as determined by 1997So08 from studies of ^{73}Ge(p,nγ) reaction.

θ 511-keV annihilation radiation: weighted-mean relative emission probability of 126 (3) % compares with a value of 133 (1) % calculated from the total absolute positron emission probability and normalisation factor - uncertainty increased artificially to derive a more acceptable relative emission probability of 133 (8) %.

Δ Unplaced in proposed decay scheme.

¶ Unresolved doublet derived from defined decay scheme.

$ Relative emission probability of 865.45-keV γ ray calculated to be 0.02 (1) % from relative emission probability ratio of 865.45- and 783.32-keV γ rays depopulating 1293.37-keV nuclear level of ^{73}As (relative emission probabilities of 18.1 (151) and 69.78 (21), respectively, from 1997So08); as a consequence, the relative emission probability of 865.17-keV γ ray depopulating the 1293.09-keV nuclear level of ^{73}As was defined as 0.540 (17) – 0.02 (1) → 0.52 (2) %.

Φ Gamma ray depopulates proposed 1850.59-keV nuclear level of ^{73}As.

† Gamma ray depopulates proposed 1961.8-keV nuclear level of ^{73}As.

‡ Gamma ray depopulates proposed 2434.1-keV nuclear level of ^{73}As.

▲ Gamma ray depopulates proposed 2476.1-keV nuclear level of ^{73}As.

The measured relative emission probability of the 67.039-keV gamma ray proved to be particularly problematic from the point of view of the derived depopulation of the 67.039 nuclear level to the ground state of ^{73}As. Based on a calculated relative transition probability of 102.83 (21) and 100 % M1 total internal conversion coefficient of 0.272 (4), a relative emission probability of 80.8 (3) % was calculated in comparison to a weighted-mean value of 73 (7) % from the measured data:

$$TP_{\gamma}^{rel}(67.039\ keV) \;=\; \sum_{67.039\ keV}^{\gamma\ population} TP_{\gamma}^{rel} \;+\; total\ relative\ P_{EC_{0,1}}$$

$$= \;101.590\ (20) \;+\; 1.24\ (21) \;=\; 102.83\ (21)$$

Therefore:

$$P_{\gamma}^{rel}(67.039\ keV) \;=\; \frac{TP_{\gamma}(67.039\ keV)}{(1\ +\ total\ ICC_{67.039\ keV})} \;=\; \frac{102.83\ (21)}{1.272\ (4)} \;=\; 80.8\ (3)$$

Thus, a relative emission probability of 81 (8) % could be adopted for the 67.039-keV gamma ray, whereby the recommended uncertainty could be brought into a sensible degree of alignment with the measured data and their uncertainties of 1969Ma21, 1970Me20 and 1980Te01.

An alternative procedure would be to modify the total internal conversion coefficient to a value of 0.409 (14) in order to achieve good agreement between the weighted-mean relative emission probability of 73 (7) % and the calculated relative transition probability of 102.83 (21) for the 67.039-keV gamma transition:

$$P_{\gamma}^{rel}(67.039\ keV) \;=\; \frac{TP_{\gamma}^{rel}(67.039\ keV)}{(1+\ total\ ICC_{67.039\ keV})}$$

and therefore $(1\ +\ total\ ICC_{67.039\ keV}) \;=\; \frac{TP_{\gamma}^{rel}(67.039\ keV)}{P_{\gamma}^{rel}(67.039\ keV)} \;=\; \frac{102.83\ (21)}{73\ (7)} \;=\; 1.409\ (14)$

$total\ ICC(67.039\ keV) \;=\; 0.409\ (14)$, which defines a calculated mixing ratio (δ) of 0.211 (10).

Further studies of this gamma-ray emission are merited to improve understanding and confidence in this important feature of the decay scheme of ^{73}Se.

Multipolarities, and Internal Conversion and Internal-Pair Coefficients

The nuclear level scheme specified by Singh has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2004Si08). Various γ-γ coincidence studies have resulted in the determination of a limited number of transition types and mixing ratios: 100 % M1 for the 67.039-keV gamma ray, (99.88 % M2 + 0.12 % E3) for the 360.866-keV gamma ray, and 100 % E3 for the 427.905-keV gamma ray (1963Bo26, 1967Ra08, 1969Ma21, 1970Me20, 1970Qu03, 1980Te01 and 1988Be39). While various E1 and E2 gamma transitions could also be identified, mixing ratios for all of the low-intensity (M1 + E2) gamma rays have not been defined and quantified. The weighted-mean emission probability and resulting transition probability of the substantial 67.039-keV gamma emission is in some disagreement with the rest of the proposed decay-scheme data. As described above, this problem can be addressed by either arbitrarily increasing the relative emission probability from 73 (7) % to 81 (8) % for a 100 % M1 transition, or modifying the mixing ratio to 0.211 (10) to give a multipolarity of (95.7 % M1 + 4.3 % E2). However, the weighted mean value of the measured relative emission probabilities has been adopted to be 73 (7) %, with the internal conversion coefficients defined for a 100 % M1 transition (α_{total} of 0.272 (4)).

Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45). A significant number of gamma transitions undergo decay via internal-pair formation, and the coefficient for this process has also been quantified in a few cases from the tabulations of 2008Ki07.

Gamma-ray emissions: multipolarities, and theoretical internal-conversion (frozen orbital approximation) and internal-pair formation coefficients.

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	$\alpha_{totalICC}$	α_{IPF}	α_{total}
67.039 (8)	**100 % M1 (1967Ra08, 1970Qu03, 1988Be39)**	0.241 (4)	0.026 4 (4)	0.004 6	0.272 (4)	–	0.272 (4)
	or 95.7 % M1+ 4.3 % E2 δ = 0.211 (10)	0.356 (12)	0.045 4 (19)	0.007 6	0.409 (14)	–	0.409 (14)
360.866 (23)	99.88 % M2 + 0.12 % E3 δ = − 0.035 (10) (1963Bo26, 1970Qu03, 1988Be39)	0.011 65 (17)	0.001 286 (18)	0.000 214	0.013 15 (19)	–	0.013 15 (19)
427.905 (21)	E3	0.01195 (17)	0.001 397 (20)	0.000 223	0.013 57 (19)	–	0.013 57 (19)
443.015 (19)	(E1)	0.000 926 (13)	0.000 095 5 (14)	0.000 015 5	0.001 037 (15)	–	0.001 037 (15)
510.053 (17)	(E1)	0.000 650 (10)	0.000 067 0 (10)	0.000 011	0.000 728 (11)	–	0.000 728 (11)
557.50 (11)	(M1 + E2)	–	–	–	–	–	–
575.45 (9)	(M1 + E2)	–	–	–	–	–	–
600.3 (3)$^{\Delta}$	–	–	–	–	–	–	–
609.22 (4)	(E2)	0.001 258 (18)	0.000 132 7 (19)	0.000 021 3	0.001 412 (20)	–	0.001 412 (20)
682.04 (11)	(E1)	0.000 330 (5)	0.000 033 8 (5)	0.000 005 2	0.000 369 (6)	–	0.000 369 (6)
700.27 (13)	(M1 + E2)	–	–	–	–	–	–
765.09 (7)	(M1 + E2)	–	–	–	–	–	–
783.32 (4)	(M1 + E2)	–	–	–	–	–	–
793.0 (5)$^{\Delta}$	–	–	–	–	–	–	–
813.46 (6)	(E2)	0.000 573 (8)	0.000 059 7 (9)	0.000 009 3	0.000 642 (9)	–	0.000 642 (9)
818.84 (5)	(M1 + E2)	–	–	–	–	–	–
847.22 (7)	(M1 + E2)	–	–	–	–	–	–
856.81 (5)	(E1)	0.000 203 (3)	0.000 020 7 (3)	0.000 003 3	0.000 227 (4)	–	0.000 227 (4)
865.17 (10)	(M1 + E2)	–	–	–	–	–	–
865.45 (3)	(M1 + E2)	–	–	–	–	–	–
872.99 (12)	(E2)	0.000 479 (7)	0.000 049 9 (7)	0.000 008 1	0.000 537 (8)	–	0.000 537 (8)
887.28 (10)	(M1 + E2)	–	–	–	–	–	–
900.97 (5)	(M1 + E2)	–	–	–	–	–	–
926.721 (14)	(M1 + E2)	–	–	–	–	–	–
930.09 (15)$^{\Delta}$	–	–	–	–	–	–	–
968.0 (2)	–	–	–	–	–	–	–
982.73 (8)	(M1 + E2)	–	–	–	–	–	–
993.759 (12)	(E2)	0.000 350 (5)	0.000 036 3 (5)	0.000 005 7	0.000 392 (6)	–	0.000 392 (6)
1002.60 (10)	(E1)	0.000 148 4 (21)	0.000 015 17 (22)	0.000 002 4	0.000 166 0 (24)	–	0.000 166 0 (24)
1018.25 (7)	(M1 + E2)	–	–	–	–	–	–
1036.48 (9)	(M1 + E2)	–	–	–	–	–	–

1111.004 (23)	(M1 + E2)	–	–	–	–	–	–
1153.97 (24)	(M1 + E2)	–	–	–	–	–	–
1159.0 (4)	–	–	–	–	–	–	–
1208.09 (7)	(E1)	0.000 105 0 (15)	0.000 010 72 (15)	0.000 001 78	0.000 117 5 (15)	0.000 052 5 (8)	0.000 170 0 (24)
1215.4 (8)$^{\Delta}$	–	–	–	–	–	–	–
1226.32 (3)	(E1)	0.000 102 3 (15)	0.000 010 43 (15)	0.000 001 67	0.000 114 4 (15)	0.000 064 3 (9)	0.000 179 (3)
1249.9 (2)$^{\Delta}$	–	–	–	–	–	–	–
1275.13 (7)	(M2)	0.000 394 (6)	0.000 040 8 (6)	0.000 006 8	0.000 442 (6)	0.000 004 16 (6)	0.000 446 (7)
1308.94 (13)	(E1)	0.000 091 2 (13)	0.000 009 30 (13)	0.000 001 53	0.000 102 0 (13)	0.000 120 3 (17)	0.000 222 (4)
1317.85 (6)	(E1)	0.000 090 2 (13)	0.000 009 19 (13)	0.000 001 50	0.000 100 8 (13)	0.000 126 1 (18)	0.000 227 (4)
1323.81 (20)$^{\Delta}$	–	–	–	–	–	–	–
1340.53 (5)	(E2)	0.000 180 (3)	0.000 018 5 (3)	0.000 003 0	0.000 201 (3)	0.000 037 6 (6)	0.000 239 (4)
1406.03 (11)	(M1 + E2)	–	–	–	–	–	–
1422.67 (6)	(M1 + E2)	–	–	–	–	–	–
1439.0 (2)	–	–	–	–	–	–	–
1451.7 (2)	–	–	–	–	–	–	–
1482.20 (6)	(M1 + E2)	–	–	–	–	–	–
1547.48 (11)	(M1 + E2)	–	–	–	–	–	–
1670.59 (10)	(M1 + E2)	–	–	–	–	–	–
1738.4 (5)$^{\Delta}$	–	–	–	–	–	–	–
1752.73 (10)	(M1 + E2)	–	–	–	–	–	–
1801.56 (6)	(M1 + E2)	–	–	–	–	–	–
1847.8 (3)$^{\Delta}$	–	–	–	–	–	–	–
1883.69 (6)	(M1 + E2)	–	–	–	–	–	–
1889.57 (20)$^{\Delta}$	–	–	–	–	–	–	–
1972.79 (23)	(M1 + E2)	–	–	–	–	–	–
2006.2 (4)	–	–	–	–	–	–	–
2023.9 (3)$^{\Delta}$	–	–	–	–	–	–	–
2048.2 (2)	–	–	–	–	–	–	–
2054.93 (23)	(M1 + E2)	–	–	–	–	–	–
2156.15 (11)	(E1)	0.000 041 3 (6)	0.000 004 19 (6)	0.000 000 69	0.000 046 1 (6)	0.000 739 (11)	0.000 785 (11)
2170.5 (3)$^{\Delta}$	–	–	–	–	–	–	–
2517.00 (11)	(M1 + E2)	–	–	–	–	–	–

$^{\Delta}$ Unplaced in proposed decay scheme.

Recommended gamma-ray energies, relative and absolute emission probabilities, and transition probabilities.

	E_γ (keV)	P_γ^{rel}	P_γ^{abs}	Transition probability (%)
$\gamma_{1,0}$	67.039 (8)	73 (7) **100 % M1** ↔ (95.7 % M1 + 4.3 % E2)	70.7 → 71 (7) **100 % M1** ↔ (95.7 % M1 + 4.3 % E2)	**90 (9)** **100 % M1** ↔ 100.0 (95.7 % M1 + 4.3 % E2)
$\gamma_{2,1}$	360.866 (23)	100	96.91 (20)	98.18 (20)
$\gamma_{2,0}$	427.905 (21)	0.080 (15)	0.078 (14)	0.079 (14)
$\gamma_{3,1}$	443.015 (19)	0.052 (3)	0.050 (3)	0.050 (3)
$\gamma_{3,0}$	510.053 (17)	0.27 (3)	0.26 (3)	0.26 (3)
$\gamma^{\pm}$	511	126 (3) → 133 (8)	129 (8)	–
$\gamma_{11,8}$	557.50 (11)	0.054 (2)	0.052 (2)	0.052 (2)
$\gamma_{11,7}$	575.45 (9)	0.150 (7)	0.146 (7)	0.146 (7)
$\gamma_{-1,1}$	600.3 (3)$^{\Delta}$	0.021 (3)	0.020 (3)	0.020 (3)
$\gamma_{5,2}$	609.22 (4)	0.051 (4)	0.049 (4)	0.049 (4)
$\gamma_{14,9}$	682.04 (11)	0.020 (2)	0.019 (2)	0.019 (2)
$\gamma_{14,7}$	700.27 (13)	0.045 (2)	0.044 (2)	0.044 (2)
$\gamma_{7,3}$	765.09 (7)	0.131 (2)	0.127 (2)	0.127 (2)
$\gamma_{9,3}$	783.32 (4)	0.060 (2)	0.058 (2)	0.058 (2)
$\gamma_{-1,2}$	793.0 (5)$^{\Delta}$	0.066 (2)	0.064 (2)	0.064 (2)
$\gamma_{11,5}$	813.46 (6)	0.009 (1)	0.009 (1)	0.009 (1)
$\gamma_{10,3}$	818.84 (5)	0.037 (2)	0.036 (2)	0.036 (2)
$\gamma_{7,2}$	847.22 (7)	0.081 (6)	0.078 (6)	0.078 (6)
$\gamma_{11,4}$	856.81 (5)	0.024 (6)	0.023 (6)	0.023 (6)
$\gamma_{8,2}$	865.17 (10)	0.52 (2)	0.50 (2)	0.50 (2)
$\gamma_{9,2}$	865.45 (3)	0.02 (1)	0.02 (1)	0.02 (1)
$\gamma_{12,5}$	872.99 (12)	0.039 (7)	0.038 (7)	0.038 (7)
$\gamma_{15,9}$	887.28 (10)	0.011 (8)	0.011 (8)	0.011 (8)
$\gamma_{10,2}$	900.97 (5)	0.139 (2)	0.135 (2)	0.135 (2)
$\gamma_{4,1}$	926.721 (14)	0.004 (1)	0.004 (1)	0.004 (1)
$\gamma_{-1,3}$	930.09 (15)$^{\Delta}$	0.005 (1)	0.005 (1)	0.005 (1)
$\gamma_{13,4}$	968.0 (2)	0.012 (5)	0.012 (5)	0.012 (5)
$\gamma_{16,10}$	982.73 (8)	0.035 (1)	0.034 (1)	0.034 (1)
$\gamma_{4,0}$	993.759 (12)	0.005 (1)	0.005 (1)	0.005 (1)
$\gamma_{15,6}$	1002.60 (10)	0.004 (1)	0.004 (1)	0.004 (1)
$\gamma_{16,9}$	1018.25 (7)	0.055 (2)	0.053 (2)	0.053 (2)
$\gamma_{16,7}$	1036.48 (9)	0.015 (1)	0.015 (1)	0.015 (1)
$\gamma_{6,1}$	1111.004 (23)	0.207 (2)	0.201 (2)	0.201 (2)
$\gamma_{19,10}$	1153.97 (24)	0.005 (1)	0.005 (1)	0.005 (1)
$\gamma_{17,7}$	1159.0 (4)	0.003 (1)	0.003 (1)	0.003 (1)
$\gamma_{7,1}$	1208.09 (7)	0.004 (1)	0.004 (1)	0.004 (1)
$\gamma_{-1,4}$	1215.4 (8)$^{\Delta}$	0.065 (10)	0.063 (10)	0.063 (10)
$\gamma_{9,1}$	1226.32 (3)	0.003 (2)	0.003 (2)	0.003 (2)
$\gamma_{-1,5}$	1249.9 (2)$^{\Delta}$	0.004 (1)	0.004 (1)	0.004 (1)
$\gamma_{7,0}$	1275.13 (7)	0.007 (1)	0.007 (1)	0.007 (1)
$\gamma_{20,7}$	1308.94 (13)	0.004 (1)	0.004 (1)	0.004 (1)
$\gamma_{16,4}$	1317.85 (6)	0.006 (1)	0.006 (1)	0.006 (1)
$\gamma_{-1,6}$	1323.81 (20)$^{\Delta}$	0.007 (1)	0.007 (1)	0.007 (1)
$\gamma_{11,3}$	1340.53 (5)	0.071 (2)	0.069 (2)	0.069 (2)
$\gamma_{20,6}$	1406.03 (11)	0.002 (1)	0.002 (1)	0.002 (1)
$\gamma_{11,2}$	1422.67 (6)	0.139 (5)	0.135 (5)	0.135 (5)
$\gamma_{18,5}$	1439.0 (2)	0.002 (1)	0.002 (1)	0.002 (1)
$\gamma_{13,3}$	1451.7 (2)	0.006 (2)	0.006 (2)	0.006 (2)
$\gamma_{12,2}$	1482.20 (6)	0.023 (1)	0.022 (1)	0.022 (1)
$\gamma_{14,2}$	1547.48 (11)	0.032 (1)	0.031 (1)	0.031 (1)
$\gamma_{15,3}$	1670.59 (10)	0.005 (1)	0.005 (1)	0.005 (1)
$\gamma_{-1,7}$	1738.4 (5)$^{\Delta}$	0.002 (1)	0.002 (1)	0.002 (1)
$\gamma_{15,2}$	1752.73 (10)	0.011 (1)	0.011 (1)	0.011 (1)
$\gamma_{16,3}$	1801.56 (6)	0.020 (5)	0.019 (5)	0.019 (5)
$\gamma_{-1,8}$	1847.8 (3)$^{\Delta}$	0.008 (1)	0.008 (1)	0.008 (1)
$\gamma_{16,2}$	1883.69 (6)	0.031 (2)	0.030 (2)	0.030 (2)
$\gamma_{-1,9}$	1889.57 (20)$^{\Delta}$	0.003 (1)	0.003 (1)	0.003 (1)

$\gamma_{19,3}$	1972.79 (23)	0.001 (1)	0.001 (1)	0.001 (1)
$\gamma_{17,2}$	2006.2 (4)	0.002 (1)	0.002 (1)	0.002 (1)
$\gamma_{-1,10}$	2023.9 (3)$^{\Delta}$	0.002 (1)	0.002 (1)	0.002 (1)
$\gamma_{18,2}$	2048.2 (2)	0.001 (1)	0.001 (1)	0.001 (1)
$\gamma_{19,2}$	2054.93 (23)	0.003 (1)	0.003 (1)	0.003 (1)
$\gamma_{20,2}$	2156.15 (11)	0.005 (1)	0.005 (1)	0.005 (1)
$\gamma_{-1,11}$	2170.5 (3)$^{\Delta}$	0.002 (1)	0.002 (1)	0.002 (1)
$\gamma_{20,1}$	2517.00 (11)	0.005 (1)	0.005 (1)	0.005 (1)

$^{\Delta}$ Unplaced in proposed decay scheme.

Energies and emission probabilities of noteworthy internal conversion electrons.

		Energy (keV)	Electrons per 100 disint.
$ec_{1,0\ T}$	(As)	55.172 – 67.037	19 (11)
$ec_{1,0\ K}$	(As)	55.172 (8)	17 (10)
$ec_{1,0\ L}$	(As)	65.513 – 65.716	1.8 (10)
$ec_{1,0\ M+}$	(As)	66.836 – 67.037	0.32 (18)
$ec_{2,1\ T}$	(As)	349.00 – 360.86	1.27 (30)
$ec_{2,1\ K}$	(As)	349.00 (3)	1.13 (25)
$ec_{2,1\ L}$	(As)	359.34 – 359.54	0.12 (3)
$ec_{2,1\ M+}$	(As)	360.66 – 360.86	0.021 (5)

EC/β+ Transitions

Energies

All EC/β^+ energies were derived from the structural details of the proposed decay scheme. The nuclear level energies of 2004Si08 and evaluated Q_{EC}-value of 2725 (7) keV (2012Wa38) were used to determine the recommended energies and uncertainties of the EC transitions and β^+ emissions.

Transition and Emission Probabilities

A large majority of the EC transition probabilities were derived for the population-depopulation imbalances of the relative emission probabilities of the gamma rays, their theoretical internal conversion and internal-pair formation coefficients. A value of 0.9691 (20) was adopted as the normalisation factor in order to determine the absolute transition and emission probabilities of the EC and β^+ particles from their resulting relative transition and emission probabilities. Component EC and β^+ transition and emission probabilities were determined from EC/β^+ ratios (1971Go40), and log*ft* values and average $E_{\beta+}$ energies were derived by means of the LOGFT code. Fractional EC probabilities P_K, P_L, P_M and P_N were calculated by means of the EC-CAPTURE code (1998Sc28) as developed from the data tabulations of 1995ScZY. Possible EC transitions directly to the 1293.37, 1037.13-, 993.766- and 510.055-keV nuclear levels of ^{73}As were assumed to be zero, based on gamma population-depopulation balances and/or spin-parity considerations, while EC decay directly to the ground state was assigned a value of zero from a spin-parity assessment alone (third forbidden non-unique (3, yes)).

The absolute emission probability of the 511-keV annihilation radiation was derived from the total absolute positron emission probability of 64.6 (4) % as determined during the evaluation of the EC/β^+ transitions/emissions:

$$absolute\ P_\gamma^{\pm} = 2 \times 64.6\ (4) = 129.2\ (8)\ \% \rightarrow 129\ (1)\ \%$$

$$[\ relative\ P_\gamma^{\pm} = \frac{absolute\ P_\gamma^{\pm}}{F} = \frac{129.2\ (8)}{0.9691\ (20)} = 133.3\ (9)\ \% \rightarrow 133\ (1)\ \%\ ]$$

where F is the normalisation factor for the gamma-ray emission probabilities. Recommended uncertainties have been artificially increased:

$relative\ P_\gamma^{\pm}$ = 133 (8) %, and therefore $absolute\ P_\gamma^{\pm}$ = 129 (8) %

to ensure full coverage of the range of measured relative emission probabilities for the annihilation radiation (i.e. 125 (12) %, 126 (3) % and 128 (13) % → 133 (8) %).

A decay scheme was derived that consists of 16EC/6β^+ transitions and 53 gamma-ray emissions. Substantial 511-keV annihilation radiation was also observed. Eleven additional gamma-ray emissions of reasonably low intensity could not be placed in the proposed decay scheme.

Recommended energies and transition probabilities of the EC/β^+ decay of ^{73}Se.

	E_{EC} (keV)*	$E_{\beta+}$ (keV)	Av. $E_{\beta+}$ (keV)	P_{EC}(total)	ϵ/β+ (theory) 1971Go40	P_{EC}	$P_{\beta+}$	^{73}Se	^{73}As	transition type	log *ft*	P_K	P_L	P_M	P_N
$EC_{0,20}$	141 (7)	−	−	0.0155 (20)	−	0.0155 (20)	−	9/2 +	(7/2, 9/2 −)	(1st forbidden non-unique)	6.2	0.8646 (19)	0.1136 (16)	0.0199 (5)	0.0020 (2)
$EC_{0,19}$	242 (7)	−	−	0.0087 (20)	−	0.0087 (20)	−	9/2 +	(7/2, 9/2 +)	allowed	7.0	0.8723 (16)	0.1072 (13)	0.0186 (4)	0.0018 (2)
$EC_{0,18}$	249 (7)	−	−	0.0029 (10)	−	0.0029 (10)	−	9/2 +	(11/2, 15/2)	(allowed)	7.5	0.8726 (16)	0.1070 (13)	0.0186 (4)	0.0018 (2)
$EC_{0,17}$	291 (7)	−	−	0.0048 (19)	−	0.0048 (19)	−	9/2 +	3/2 +, 5/2 +	[2nd forbidden non-unique]	7.4	0.8740 (16)	0.1058 (13)	0.0184 (4)	0.0018 (1)
$EC_{0,16}$	413 (7)	−	−	0.157 (6)	−	0.157 (6)	−	9/2 +	(7/2, 9/2 +)	(allowed)	6.2	0.8764 (16)	0.1038 (13)	0.0180 (4)	0.0018 (1)
$EC_{0,15}$	544 (7)	−	−	0.030 (8)	−	0.030 (8)	−	9/2 +	(7/2, 9/2 +)	(allowed)	7.1	0.8778 (15)	0.1027 (13)	0.0178 (4)	0.0017 (1)
$EC_{0,14}$	750 (7)	−	−	0.094 (3)	−	0.094 (3)	−	9/2 +	(7/2, 9/2, 11/2 +)	(allowed)	6.9	0.8789 (15)	0.1018 (13)	0.0176 (4)	0.0017 (1)
$EC_{0,13}$	763 (7)	−	−	0.017 (5)	−	0.017 (5)	−	9/2 +	(3/2, 5/2, 7/2)	(allowed)	7.7	0.8790 (15)	0.1017 (13)	0.0176 (4)	0.0017 (1)
$EC_{0,12}$	815 (7)	−	−	0.060 (7)	−	0.060 (7)	−	9/2 +	(9/2 +, 11/2)	(allowed)	7.2	0.8792 (15)	0.1016 (13)	0.0175 (4)	0.0017 (1)
$EC_{0,11}$	874 (7)	−	−	0.433 (11)	−	0.433 (11)	−	9/2 +	(9/2) +	(allowed)	6.4	0.8794 (15)	0.1014 (12)	0.0175 (4)	0.0017 (1)
$EC_{0,10}$	1396 (7)	374 (7)	164 (3)	0.132 (3)	37.50	0.129 (3)	0.0034 (2)	9/2 +	(7/2, 9/2) +	(allowed)	7.3	0.8804 (15)	0.1006 (12)	0.0173 (4)	0.0017 (1)
$EC_{0,8}$	1432 (7)	410 (7)	179 (3)	0.452 (20)	26.30	0.435 (19)	0.017 (2)	9/2 +	(11/2) +	(allowed)	6.8	0.8804 (15)	0.1006 (12)	0.0173 (4)	0.0017 (1)
$EC_{0,7}$	1450 (7)	428 (7)	187 (3)	0.006 (2)	22.39	0.0057 (19)	0.0003 (1)	9/2 +	(7/2) +	(allowed)	8.7	0.8804 (15)	0.1006 (12)	0.0173 (4)	0.0017 (1)
$EC_{0,6}$	1547 (7)	525 (7)	228 (3)	0.195 (2)	10.59	0.178 (2)	0.017 (1)	9/2 +	(7/2) −	(1st forbidden non-unique)	7.3	0.8805 (15)	0.1005 (12)	0.0173 (4)	0.0017 (1)
$EC_{0,2}$	2297 (7)	1275 (7)	555 (3)	97.24 (20)	0.522	33.3 (5)	63.9 (5)	9/2 +	9/2 +	allowed	5.36	0.8810 (15)	0.1001 (12)	0.0172 (4)	0.0017 (1)
$EC_{0,1}$	2658 (7)	1636 (7)	745 (3)	1.2 (2)	0.741	0.51 (9)	0.69 (11)	9/2 +	5/2 −	1st forbidden unique	8.7^{1u}	0.8811 (15)	0.1000 (12)	0.0172 (4)	0.0017 (1)
				∑ 100.0479		∑ 35.3806	∑ 64.6277								
						∑ 100.0083									

* Determined from the nuclear level energies of 2004Si08 and Q-value of 2725(7) keV (2012Wa38).

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.02, 28 February 2012), as described in 2000Sc47. This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

The inability to obtain a sound and satisfactory balance with respect to the population-depopulation of the 67.039-keV nuclear level of ^{73}As could have arisen as a consequence of either a poorly quantified emission probability for the 67.039-keV gamma ray when identified to be a 100 % M1 transition, or a suitably well-defined emission probability for the 67.039-keV gamma ray with inappropriate ICC data. A weighted-mean absolute emission probability of 71 (7) % has been adopted for the 67.039-keV gamma ray with a multipolarity of 100 % M1 rather than (95.7 % + 4.3 % E2). Such a difference impacts on the X-ray and Auger-electron data as shown below:

K and L X-ray energies and emission probabilities of ^{73}Se.

			Energy (keV)	Multipolarity of 67.039-keV gamma transition			
				100 % M1		(95.7 % M1 + 4.3 % E2) XX	
				Photons per 100 disint.	Relative probability	Photons per 100 disint.	Relative probability
XL		(As)	1.120 – 1.524	1.05 (3)	6.48	1.24 (4)	6.56
	XL_l	(As)	1.120	0.0270 (10)		0.0316 (14)	
	XL_α	(As)	1.282	0.613 (21)		0.72 (3)	
	XL_η	(As)	1.155	0.0152 (7)		0.0178 (9)	
	XL_β	(As)	1.317 – 1.388	0.397 (17)		0.466 (23)	
	XL_γ	(As)	1.524	0.00230 (9)		0.00268 (11)	
XK_α	$XK_{\alpha2}$	(As)	10.50814 (9)	8.3 (3)	51.2	9.7 (5)	51.3
	$XK_{\alpha1}$	(As)	10.54380 (9)	16.2 (6)	100	18.9 (9)	100
$XK'_{\beta1}$	$XK_{\beta3}$	(As)	11.7204 (5)	}		}	
	$XK_{\beta1}$	(As)	11.7263 (2)	} 3.70 (14)	22.8	} 4.31 (21)	22.8
	$XK_{\beta5}$	(As)	11.821 (1)	}		}	
$XK'_{\beta2}$	$XK_{\beta2}$	(As)	11.8643 (3)	0.140 (7)	0.86	0.163 (10)	0.86

Auger-electron energies and emission probabilities of ^{73}Se.

		Energy (keV)	Multipolarity of 67.039-keV gamma transition			
			100 % M1		(95.7 % M1 + 4.3 % E2)	
			Electrons per 100 disint.	Relative probability	Electrons per 100 disint.	Relative probability
e_{AK}	(As)		21.0 (8)		24.4 (12)	
	KLL	8.746 – 9.149	15.7 (6)	100	18.3 (9)	100
	KLX	10.114 – 10.541	4.91 (19)	31.3	5.7 (3)	31.1
	KXY	11.460 – 11.862	0.384 (17)	2.45	0.447 (24)	2.44
e_{AL}	(As)	0.90 – 1.23	65.3 (15)	416	76.5 (22)	418

As: ω_K = 0.575 (4); ϖ_L = 0.0155 (5); n_{KL} = 1.232 (4) were taken from 1996Sc06.

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

A Q_{EC}-value of 2725 (7) keV has been adopted from the atomic mass evaluation of Wang *et al.* (2012Wa38) while in the course of formulating the decay scheme of ^{73}Se. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{73}Se EC-decay process (i.e. EC/β^+, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \; x \; P_i) = 2718\ (16)\ \text{keV}$$

Percentage deviation from the Q-value of Wang *et al.* is 0.3 (6) %, which supports the derivation of a reasonably consistent decay scheme with a large variant despite known inadequacies identified with the gamma depopulation of the first excited state of ^{73}As (i.e. 67.039-keV nuclear level).

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