

⁵⁹Fe – Comments on evaluation of decay data by M.M. Bé and V. Chisté

1. Decay scheme

This decay scheme was well studied (Bérényi, Béraud, Collin, Ferguson, Heath, Pancholi, Metzger, Raman, etc.) so that the existence of beta transitions and the spin and parity of the ⁵⁹Co levels are clearly established. Some authors (Mukerji, Raman) carried out experiments in order to measure the weak β - branches. No clear evidence of a β -branching to the 1190 keV level was found, if this transition exists its branching ratio has an upper limit of 1×10^{-4} .

2. Nuclear Data

⁵⁹Fe half-life (in days)

Author	NSR	Value	Uc	Method
Metzger	52Me53	45.0	3.0	NaI
Keene	58Ke26	44.56	0.03	ionisation chamber
Pierroux	59Pi43	45.60	0.08	Electrometer à lames vibrantes
Fuschini	60Fu03	63.1	0.8	
Heath	60He06	45.0	5.0	NaI
Subba Rao	60Su10	46.5	1.0	
Wortman	63Wo01	45.0	3.0	
Emery	72Em01	44.5	0.2	NaI
Visser	73Vi13	44.75	0.04	NaI (s x 3)
Alstad	75Al02	45.3	0.3	Gas flow proportional counter
Houtermans	80Ho17	44.496	0.007	4 π - γ
Walz	83Wa26	44.53	0.07	4 π - γ ionisation chamber
Unterweger	92Un01	44.5074	0.0072	
Martin	97Ma75	44.472	0.008	4 π - γ ionisation chamber

The value from Fuschini was omitted due to its large deviation from the others.

The values from Subba Rao, Pierroux were rejected as outlier (Chauvenet' s criteria).

With this set of eleven remaining values, the reduced χ^2 is 6.4 and the Lweight program recommends the unweighted mean and expanded the uncertainty : 44.74 ± 0.24 .

With these eleven values the weighted mean and the external uncertainty are : 44.498 ± 0.011 .

Taking into account the most precise values (Keene, Visser, Houtermans, Walz, Unterweger and Martin) :

- the value from Visser was rejected as outlier;

- then the reduced $\chi^2 = 4$;

- the weighted mean is 44.495 with an external uncertainty of 0.008.

Regarding the fact that the four more recent measurements are compatible with this value and (for three of them) have a similar uncertainty, the recommended value is :

44.495 \pm 0.008 d

Half-lives of ⁵⁹Co excited levelsLevel 1100 keV

- Sidhu : ≤ 50 ps
- Béraud < 14 ps

Level 1291 keV (in ns)

Author	NSR	Value	Uc
Sidhu :	67Si01	0.60	0.05
Agarwal :	67Ag03	0.59	0.02
Béraud :	67Be60	0.575	0.011
Garg :	72Ga39	0.538	0.004
Green :	72Gr05	0.564	0.020
Arens :	71Ar07	0.564	0.005

The value from Chauhan (0.516 (6)) was not taken into account : it seems that the experiment is the same as those described in Garg *et al.*

For the six values above the reduced χ^2 is 5.45 and the critical $\chi^2 = 3$. Then, the uncertainty on the value given by Garg was increased by 1.08 in order to reduce its relative weight to 50 %. The reduced χ^2 is 5.10. This set of value is not consistent and the unweighted mean is adopted : **0.572 (34) ns**.

Level 1434 keV

Arens : 210 (20) ps

2.1 Beta Transitions**Beta transition energies**

The adopted Q-value 1565.2 (6) keV is from Audi and Wapstra. It was determined from the measurements of Wortman and Metzger (see Table below)

The adopted energies and uncertainties of beta transitions are deduced from the Q-value and the levels energies and their uncertainties.

Measured beta energies are summarized in the following table :

keV	1565	475	273	132	85
Wortman	1573 \pm 3	475 \pm 3	273 \pm 5		
Berenyi		455 \pm 5	275 \pm 5		
Metzger	1560 \pm 8	462 \pm 3	271 \pm 3		
Mukerji	1566			132	85
Subba Rao	1580 \pm 20	470 \pm 6	280 \pm 6	150 \pm 10	
Raman	1575 \pm 20	461 \pm 10	268 \pm 10	128	80
<i>Evaluated</i>	1572 \pm 3	463.4 \pm 2.2	273.0 \pm 2.1	137 \pm 8	82.5 \pm 2.5
Adopted	1565.2 \pm 0.6	465.9 \pm 0.6	273.6 \pm 0.6	130.9 \pm 0.6	83.6 \pm 0.6

The 1565 keV transition is second forbidden non unique, with the shape factor given by Wortman (see below) the mean energy is 521 keV ; with the shape factor from Raman the mean energy is 584 keV ; these calculations were done with the SPEBETA program. In the Russian book Kolobachkin *et al.* the mean energy was calculated to be 523 keV.

Expecting a confirmation, the adopted value is 522 (2) keV.

Beta transition probabilities

The emission probabilities are calculated from gamma transition probability imbalance on each level. That was done for all the transitions, except for the weak 1565-keV to the ground state, the resulting values are in agreement with the experimental values (see Table below).

Taking into account the consistency of the decay scheme :

- the sum of all the transitions to the Co-59 ground state must be equal to 100 ; this leads to an intensity value of 0.12 (32) for the 1565 keV transition. This important uncertainty comes from the propagation of the uncertainties on the gamma transitions.
- the sum of all the beta transitions leaving from Fe-59 must be equal to 100 ; this gives a value of 0.13 (34) for the 1565 transition.

However, several authors measured this transition intensity and found values from 0.18 (4) % to 0.3 (1) % (Table below).

It must also be pointed out that the authors gave measured gamma emission probabilities after corrections, with a value of the $I_{\beta}(gs)$ taken as :

- 0.3% by Legrand, Béraud, Pancholi ;
- 0.18% by Miyahara.

From the previous remarks, it follows that the $I_{\beta}(gs)$ intensity is certainly greater than 0.10% (decay scheme) and less than 0.40% (experiments).

The adopted value is then : 0.25 (15) %.

Table : Measured I_{β}

Metzger (52Me53)			
1573 keV	$I_{\beta} = 0.3 (1)\%$	$\lg ft = 10.9$	
475 keV	$I_{\beta} = 54.8 (20)\%$	$\lg ft = 6.7$	
273 keV	$I_{\beta} = 44.9 (20)\%$	$\lg ft = 5.9$	
Wortman. (63Wo01) (No uncertainty given)			
1573 keV	$I_{\beta} = 0.30\%$	$\lg ft = 10.96$	shape factor $p^2 + 3.3 q^2$
475 keV	$I_{\beta} = 51.2\%$	$\lg ft = 6.74$	
273 keV	$I_{\beta} = 48.5\%$	$\lg ft = 5.92$	
Raman (74Ra13)			
1573 keV	$I_{\beta} = 0.18 (4)\%$	$\lg ft = 11.15 \pm 0.11$	shape factor $p^2 + 1.7 q^2$
475 keV	$I_{\beta} = 51 (3)\%$		
273 keV	$I_{\beta} = 47 (4)\%$		
(80-128)	$I_{\beta} = (1.4)\%$		
Berényi (60Be06) (No uncertainty given)			
1573 keV	$I_{\beta} < 0.5 \%$		
475 keV	$I_{\beta} = 55.4\%$	$\lg ft = 6.1$	
273 keV	$I_{\beta} = 44.6\%$	$\lg ft = 5.3$	

β - γ circular polarization asymmetry coefficients

Behrens (70BeZx) recommends :

For 466 β - 1099 γ : $A = -0.164 (7)$

For 273 β - 1292 γ : $A = -0.15 (2)$

2.2 Gamma transitions and internal conversion coefficients

1291 keV transition

Assuming a pure E2 transition, the theoretical ICC (from Band's tables) $a_T = 1.22 \cdot 10^{-4}$ is consistent with the experimental one from Metzger (52Me53) $\alpha_T = 1.35 (6) \cdot 10^{-4}$.

Other measurements :

Metzger (52Me53), $\alpha_K = 1.19 (6) \cdot 10^{-4}$

Hinman (53Hi02), $\alpha_T = 1.06 (16) \cdot 10^{-4}$

Collin (64Co34), $\alpha_T = 1.07 (8) \cdot 10^{-4}$

K.S.Krane *et al.* (1976Kr10) suggests a M3/E2 mixture of $\delta = -0.033 (30)$, that does not change the ICC value significantly.

1099 keV transition

Assuming a pure E2 transition, the theoretical ICC (from Band's tables) $a_T = 1.75 \cdot 10^{-4}$ is consistent with the experimental one from Metzger (52Me53) $\alpha_T = 1.87 (7) \cdot 10^{-4}$.

Other measurements :

Metzger(52Me53), $\alpha_K = 1.35 (6) \cdot 10^{-4}$

Hinman(53Hi02), $\alpha_T = 1.84 (27) \cdot 10^{-4}$

Collin(64Co34), $\alpha_T = 1.36 (10) \cdot 10^{-4}$

334 keV transition E2/M1

The measured values of the mixing ratio are the following :

Author	Delta
Pancholi	- 0.12 (6)
Eriksson	- 0.12 (4)
Arens	+ 0.05 + 0.03 - 0.07 or - 1.8 + 0.4 - 0.6
Adopted value	- 0.12 (6)
ICC (Band)	0.002 (1)

142 keV transition E2/M1

The measured values of the mixing ratio are the following :

Author	Delta
Pancholi	- 0.15 (6) < δ < 0.026
Eriksson	- 0.006 (12)
Arens	0.028 + 0.009 - 0.014 or - 1.78 + 0.15 - 0.20
Adopted value (from Krane 1977Kr13)	- 0.008 (7)
ICC (Band)	0.0160 (1)

192 keV transition E2/M1

The measured values of the mixing ratio are the following :

Author	Delta
Pancholi	- 0.22 (2)
Eriksson	0.21 (2)
Arens	- 0.21 (2) or $\delta > 14$
Bajaj	0.22 (2)
Collin	- 0.296 (23)
Adopted value	0.21 (1)
ICC (Band)	0.00899 (15)

Gamma emissionsGamma emission energies

The gamma emission energy of the following lines are from Helmer (2000He14) :

142.651 ± 0.002

192.349 ± 0.005

1099.245 ± 0.003

1291.590 ± 0.006

Others are from Pancholi.

Gamma emission intensities

Eight published papers describe measurements of the gamma emission intensities, all the values are given in absolute values.

Heath *et al.* do not give uncertainty, therefore these values are omitted.

The results given by Béraud *et al.* are with uncertainties of the order of 10%, they are not omitted but their relative weight is generally weak, as well as those of the values given by Mukerji *et al.*

J.Legrand *et al.* (70Le03), carried out β - γ coincidences measurements and deduced I_γ absolute values, assuming that the β branching to the ground state is 0.3%. The uncertainty adopted by Legrand is the sum of the statistical uncertainty assessed at 3σ and the systematic uncertainty at 1σ ; consequently, the standard deviation cannot be obtained dividing the original uncertainty by 3 and we divided the given uncertainties by 2 only.

Pancholi *et al.* (73Pa18), measured the relative values and normalized them such as $I(1099 + 1292 + 1481) = 99.7\%$, assuming $I\beta(gs) = 0.3\%$.

Miyahara *et al.* (1989Mi07), carried out activity measurements and deduced absolute values. This paper is the most recent one and gives the most precise values which contribute more than 50% in the adopted result for the two intense lines : 1099 and 1291 keV.

The following table summarizes all the values taken into account and the adopted results.

These different set of data are consistent, except for the original set of seven data for the 335 keV line where two values are outliers and are omitted (o). The adopted values are the weighted means.

keV	142	192	335	381
Mukerji	1.1 ± 0.16	3.3 ± 0.3	0.27 ± 0.03	
Legrand	0.98 ± 0.02	2.95 ± 0.04	0.24 ± 0.02	0.023 ± 0.002
Béraud	0.79 ± 0.8	2.50 ± 0.25	0.25 ± 0.05	0.022 ± 0.005
Collin	0.8 ± 0.2	2.8 ± 0.3	0.7 ± 0.3 ^(o)	
Miyahara	0.955 ± 0.030	2.851 ± 0.048	0.262 ± 0.016	
Ferguson	0.85 ± 0.15	2.4 ± 0.4	0.34 ± 0.07 ^(o)	
Pancholi	1.02 ± 0.04	3.08 ± 0.1	0.27 ± 0.01	0.018 ± 0.003
$\chi^{**2}/N-1$ (critical)	1.5 (2.8)	1.9 (2.8)	0.5	0.97
Adopted value	0.972 ± 0.015	2.918 ± 0.029	0.264 ± 0.007	0.0215 ± 0.0016

keV	1099	1291	1481
Mukerji	57.5 ± 3	42.4 ± 2.3	0.052 ± 0.006
Legrand	55.5 ± 0.8	44.1 ± 0.6	0.09 ± 0.01
Béraud	56.2 ± 5.6	43.5 ± 4.3	0.056 ± 0.012
Collin	56.5 ± 1.5	43.2 ± 1.5	
Miyahara	56.68 ± 0.22	42.99 ± 0.30	
Ferguson	56 ± 3	44 ± 3	
Pancholi	56.5 ± 1.5	43.2 ± 1.1	0.059 ± 0.006
$\chi^{**2}/N-1$ (critical)	0.4	0.5	3.6 (3.8)
Adopted value	56.59 ± 0.21	43.21 ± 0.25	0.0603 ± 0.0037

Angular correlation coefficients

Several authors determined the angular correlation coefficients. Some of them are summarized here as a matter of interest.

$192\gamma - 1099\gamma, \frac{3}{2} \overline{(M1+E2)} \frac{3}{2} \overline{(E2)} \frac{7}{2}$:

Author	NSR	A2	uc	A4	uc
Heath	60He06	0.024	0.005		
Rao	70Ra00	0.028	0.003	0.008	0.007
Arens	71Ar07	0.008	0.007		
Bajaj	72Ba**	0.008	0.004	0.004	0.008
Eriksson	73Er11	0.011	0.004	- 0.003	0.004

$335\gamma - 1099\gamma, \frac{1}{2} \overline{(M1+E2)} \frac{3}{2} \overline{(E2)} \frac{7}{2}$:

Author	A2	uc	A4	uc
Rao	- 0.043	0.003	- 0.004	0.003
Arens	- 0.064	0.011	- 0.008	0.025
Eriksson	- 0.040	0.010	- 0.006	0.0006
Bajaj	- 0.099	0.012		

$143\gamma - 1292\gamma, 1/2^-(M1+E2)3/2^-(E2)7/2^- :$

Author	A2	uc	A4	uc
Heath	- 0.069	0.005		
Rao	- 0.065	0.004	- 0.006	0.005
Arens	- 0.065	0.004		
Bajaj	- 0.070	0.005	0.014	0.015
Subrahmanyam	- 0.09	0.01		
Eriksson	- 0.070	0.003		

Conversion electrons

Conversion electron intensities were calculated from the gamma transition probabilities and the internal conversion coefficients.

Hinman(53Hi02) gives the ratio of the number of conversion electrons from the 1099 keV transition to the number of conversion electrons from the 1291 keV transition, to be equal to 1.91 (9).

There is a good agreement with the ratio (1.87) obtained from the calculated values in this evaluation.

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