^{52m}Mn – Comments on evaluation

Aurelian Luca
IFIN-HH, PO Box MG-6, Magurele, jud.Ilfov, postcode 077125, Romania

This evaluation was completed by early November 2020 and includes all literature published before this date.

Decay Scheme

^{52m}Mn decays 100% by electron capture (ε) and isomeric transition (IT) to excited levels of ^{52}Cr and to the ground state of ^{52}Mn, respectively. The IT branching ratio of 1.705 (42) % was adopted from the ^{52}Fe nuclear decay data evaluation published in the DDEP database (A. Luca, 2014, http://www.lnhb.fr/nuclear-data/nuclear-data-table). The isomer ^{52m}Mn is created within the decay of ^{52}Fe with an excitation energy of 377.749 (5) keV, according to the evaluation published by Yang and Huo (2015).

Q_{EC} value for ^{52m}Mn decay of 5089.7 (19) keV was calculated as the sum of the level excitation energy (2015Ya15) and the ^{52}Mn decay energy adopted from Wang *et al.* (2017Wa10).

The spins, parities and level energies are adopted from the most recent mass-chain evaluation published for A=52 (2015Ya15). The adopted spin and parity of the 4815.69-keV energy level of ^{52}Cr was 2^+. The lifetimes of the excited states of ^{52}Cr were adopted from Adymov *et al.* (2011Ad14).

The decay scheme is expected to be complete assuming a direct decay to the 2369.6-keV level. In 1977Ya08, the authors did not observed any gamma rays that could populate the 2369.6-keV level while its gamma transition, emitting 935.5 keV photons, was clearly seen. They assumed a feeding from higher-energy levels, leading to an incomplete decay scheme. Close study of the 33 levels up to the Q-value of ^{52m}Mn (adopted levels from 2015Ya15) led the evaluator to the conclusion that this 2369.6-keV level can only be fed through a direct decay from the initial level in ^{52m}Mn. This conclusion is limited by the current knowledge of the ^{52}Cr levels. However, it is strongly supported by the observation of photons of similar or higher energies with much smaller intensities (e.g. 4815.4 keV with an absolute intensity of 0.002 46 %).

Half-life

Three experimental half-lives were found in the literature and were used to calculate the recommended value, according to the following table:

Reference	**T½ (min)**	**T½ unc. (min)**	**Comments**
1959Ju40	21.1	0.2	
1960Ka20	21	1	
1995Ir01	22.7	3.0	Measurements on bare ions (not neutral atoms)
Crit (χ^2)	4.6		
χ^2	0.15		
UWM	21.6	0.6	
LWM	21.1		
uc(WM)int. :	0.20		
uc(WM)ext. :	0.08		
Adopted:	**21.1**	**0.2**	

The adopted data set is consistent and the recommended half-life is the weighted mean of the three listed values (LWM analysis, according to LWEIGHT4 computer program, version for MS Excel), with an uncertainty which is the maximum of the internal and external uncertainties.

New half-life measurements are needed to confirm the most recent result, published by Irnich *et al.* (1995).

Electron Capture and β⁺ Transitions

Electron capture (EC) and β^+ energies, as well as shell and sub-shells capture probabilities, were obtained from the nuclear level energies and the Q value, using the BetaShape code (2015Mo10, 2019Mo35).

There are eight electron capture transitions feeding the excited states of 1434.08 (the main EC transition), 2369.6, 2964.78, 3161.73, 3472.10, 3771.69, 3951.2 and 4815.69 keV respectively, and seven β^+ transitions, all of them in competition with the electron capture process. The maximum positron energy (2.6337 (19) MeV) is in good agreement with the experimental values measured by Katoh *et al.* (1960Ka20) of 2.61 (3) MeV, by Arbman and Svartholm (1956Ar33) of 2.631 (15) MeV and by Osborne and Deutsch (1947Os01) of 2.66 (5) MeV respectively.
The probabilities of the electron capture transitions and the β^+ transitions were calculated from the decay scheme balance and the theoretical ratio (EC/β^+) computed by the BetaShape program (2015M010, 2019Mo35). The total (EC + β^+) transition probability to the excited state of 1434.083 keV (^{52}Cr) is 97.940 (46) %. The BetaShape program was also used to calculate the log ft values for the EC and β^+ transitions.

The resulting 511-keV photon emission intensity is 193.42 (9) %.

Relative gamma emission probabilities, P_γ

Only two measurements of the gamma-ray energies and relative emission probabilities were found in the literature: Yaffe and Meyer, 1977Ya08, and Pakkanen, 1967Pa22:

	Yaffe and Meyer (1977)		Pakkanen (1967)	
(i,f)	**E_γ**	**P_γ**	**E_γ**	**P_γ *****
(1,0)*	**377.738 (5)**	17.09 ± 0.15	377.8 (4)	17 ± 3
(6,3)	**704.6 (2)**	0.29 ± 0.09		
(2,1)	**935.52 (1)****	0.2 ± 0.1		
(3,1)	**1332.62 (1)****	0.3 ± 0.1		
(1,0)	**1434.06 (1)**	1000 ± 5	1434.3	1000
(4,1)	**1530.67 (1)**	0.47 ± 0.02	1529.6 (12)	0.8 ± 0.3
(5,1)	**1727.53 (7)**	2.2 ± 0.1	1727.1 (10)	2.0 ± 0.5
(6,1)	**2038.0 (2)**	0.08 ± 0.01		
(7,1)	**2337.4 (2)**	0.07 ± 0.01		
(4,0)	**2965 (1)**	0.004 ± 0.003		
(5,0)	**3161.8 (1)**	0.22 ± 0.03	3160.0 (17)	$0.3^{+0.2}_{-0.1}$
(10,1)	**3381.5 (1)**	0.025 ± 0.005		
(7,0)	**3771.7 (2)**	0.018 ± 0.004		
(8,0)	**3951 (1)**	0.007 ± 0.003		
(10,0)	**4815.4 (2)**	0.025 ± 0.004		

* The 377.738-keV gamma ray in the Table is the IT-decay process of Mn-52m directly to the ground state of Mn-52.

** The two uncertainties of 0.01 keV each were added by the evaluator.

*** The published values were multiplied by a factor of 10, to facilitate the comparison with the data set of Yaffe and Meyer (1977).

A reference intensity of 1000 was adopted for the emission probability of the 1434.06 (1) keV gamma ray (this gamma transition follows the ^{52m}Mn electron capture and β^+ transitions populating the nuclear levels of ^{52}Cr).

The adopted γ-ray energies and relative emission probabilities are those given by Yaffe and Meyer in the Table above, with the exception of the γ-ray energy of the isomeric transition taken in 2015Ya15, consistently with the latest ^{52}Fe DDEP evaluation (A. Luca, 2014, http://www.lnhb.fr/nuclear-data/nuclear-data-table). A few very weak, yet possible γ-ray transitions were neglected in the present evaluation (e.g. 3129 keV). New accurate measurements of the γ-ray relative (and absolute) emission probabilities would be beneficial for improving the knowledge of the decay scheme.

Internal conversion coefficients

The adopted ICC are the theoretical values calculated by the BrIcc program (2008Ki07).
The main γ-ray transition is E2 (1434.06 keV).

Normalization Factor

The normalization condition requires that 98.295 (42) % of the transitions (β^+, EC, γ - with the exception of the isomeric transition) in the decay of ^{52m}Mn populate the ground state of the ^{52}Cr daughter.
A normalization factor (*N)* of 0.098 255 (42) was deduced from the above, correcting the relative γ-ray emission probabilities by the corresponding ICC and taking the 1434 keV γ transition as a reference. Using this factor and the relative γ probabilities adopted above, the absolute γ-ray emission probabilities were calculated.

Atomic Data

The fluorescence yield data, the relative K X-ray emission probabilities, the ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) were taken from Schönfeld *et al.* (1996Sc06).
The Auger electron and X-ray absolute probabilities were calculated by the EMISSION program (2000Sc47) from the related decay data (γ emission probabilities, ICC, P_{EC} probabilities, etc.) as determined above.

Data Consistency

The sum of all the energies involved (EC, γ, etc.), with the exception of the γ-ray isomeric transition, is 5089.9 (32) keV, which is in very good agreement with the Q_{EC} value: 5089.7 (19) keV. The same calculation for the isomeric transition gives an energy of 377.71 (22) keV, in excellent agreement with the transition energy 377.749 (5) keV.

References

1947Os01 R.K. Osborne, M. Deutsch. Proceedings of the American Physical Society, in Phys. Rev. 71 (1947) 460, B8. Beta plus emission energy

1956Ar33 E. Arbman, N. Svartholm. Ark. Fysik 10 (1956) 1. Beta plus emission energy

1959Ju40 J.O. Juliano, C.W. Kocher, T.D. Nainan, A.C.G. Mitchell. Phys. Rev. 113 (1959) 602. Half-life

1960Ka20 T. Katoh, M. Nozawa, Y. Yoshizawa, Y. Koh. J. Phys. Soc. Jpn. 15 (1960) 2140. Half-life, Multipolarities, Beta plus emission energies

1967Pa22 A. Pakkanen. Ann. Acad. Sci. Fenn. Series A, VI, 253 (1967) 27. Gamma ray energies, Gamma-ray relative emission probabilities

1977Ya08 R.P. Yaffe, R.A. Meyer. Phys. Rev. C16 (1977) 1581. Gamma ray energies, Gamma-ray relative emission probabilities

1995Ir01 H. Irnich, H. Geissel, F. Nolden, K. Beckert, F. Bosch, H. Eickhoff, B. Franzke, Y. Fujita, M. Hausmann, H.C. Jung, O. Klepper, C. Kozhuharov, G. Kraus, A. Magel, G. Münzenberg, F. Nickel, T. Radon, H. Reich, B. Schlitt, W. Schwab, M. Steck, K. Sümmerer, T. Suzuki, H. Wollnik. Phys. Rev. Lett. 75 (1995) 4182. Half-life

1996Sc06 E. Schönfeld, H. Janssen. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527. Atomic data

2000Sc47 E. Schönfeld, H. Janssen. Appl. Radiat. Isot. 52 (2000) 595. P(X), P(Ae)

2008Ki07 T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor Jr. Nucl. Instrum. Methods Phys. Res. A589 (2008) 202. Theoretical ICC

2011Ad14 Zh.I. Adymov, N. Burtebayev, S.B. Sakuta. Bull. Acad. Sci. USSR, Physics, vol. 75, no. 7 (2011) 914. Half-life

2015Mo10 X. Mougeot. Phys. Rev. C 91 (2015) 055504. Theoretical beta decays

2015Ya15 Yang Dong, Huo Junde. Nucl. Data Sheets 128 (2015) 185. Spin and Parity, Level energies, Half-life, Multipolarities, Mixing ratio.

2017Wa10 M. Wang, G. Audi, F.G. Kondev, W.J. Huang, S. Naimi, X. Xu, Chin. Phys. C 41, 030003 (2017) Q-value

2019Mo35 X. Mougeot. Appl. Radiat. Isot. 154 (2019) 108884. Theoretical electron capture decays