Weak branches in ^{34}Ar and ^{38}Ca β^+ decay

I.S. Towner and J.C. Hardy

In the β^+ decay of ^{34}Ar and ^{38}Ca, precisely-calibrated γ-ray yields have been measured and corresponding β branches determined. The Q_{EC} for these decays are 6.0 and 6.6 MeV respectively. Gamma rays with energy less than 3.5 MeV in ^{34}Cl and 4.0 MeV in ^{38}K have been identified [1, 2]. There is a small probability that not all the possible β-branches have been observed. How many 1^+ states are there in ^{34}Cl with an excitation energy between 3.5 and 6.0 MeV, or in ^{38}K between 4.0 and 6.6 MeV that could in principle be fed by a Gamow-Teller transition? These transitions would be very weak, too weak to be measured individually, but if there are sufficient of them they could cumulatively sum to a fraction of a percent of the total β strength. In precision work, a fraction of a percent could represent an important correction.

To answer the question, we performed some shell-model calculations. For ^{34}Cl, the model space is the full *s, d* shell with effective interactions USD of Wildenthal [3] and two more recent updates, USD-A and USD-B, of Brown and Richter [4]. These calculations identify four 1^+ states in the excitation energy window of 3.5 to 6.0 MeV with a β-decay feeding fraction greater than one part per million (ppm). We further calculated the γ-ray de-excitation of these states to identify how much of their feeding strength would have been measured in the experiment and how much would have been missed.

In the upper half of Table I we present some shell-model results. In the left two columns are the previous experimental results as recorded in the Evaluated Nuclear Structure Data File (ENSDF) [5] that show four 1^+ states at excitation energies below 3.5 MeV populated in β decay. The remainder of the Table shows three shell-model calculations that each predict four additional 1^+ states at excitation energies above 3.5 MeV that have weak β feeding strengths at the ppm level. The average sum of such feeding from the three calculations is 0.0045(16)%. Some fraction of this feeding would be counted in the β-decay experiment: the part that de-excites through one of the four lower-lying 1^+ states. However, most of the de-excitation does not proceed that way. Most de-excites by high-energy γ rays directly to the ground state or the first excited 3^+ state. This we call the missing strength as it remains unobserved in the experiment. The average missing strength from these calculations is 0.0036(13)%. The goal of the experiment is to measure and sum all the Gamow-Teller β branches and subtract the total from 100%. This yields the sought superallowed Fermi branch to the ground state in the daughter nucleus. The missing strength the shell-model calculations identify of 0.0036(13)% would be a correction to the superallowed Fermi branching ratio. In this case the correction is too small to be of any significance.

Similar calculations for ^{38}K are more difficult to complete. With a USD interaction only a few of the known states are described as the model space is very small: just two holes in a closed shell at A = 40. What is needed is a calculation that includes 4-hole, 2-particle configurations. Effective interactions for such model spaces are not under good control. We use a Millener-Kurath interaction [6] for the cross-shell Hamiltonian matrix elements and keep the model space to just three orbitals, $s_{1/2}$, $d_{3/2}$ and $f_{7/2}$. In the bottom half of Table I we give the results. As before, the left two columns give the previous results recorded in ENSDF [5], showing five 1^+ states populated at excitation energies below 4 MeV. The shell-model calculation only matches four of them. At higher excitation energy, the shell model predicts a further three 1^+ states between 4 and 6 MeV, but with very small β feeding of 0.0002% in total. Thus the missing strength is completely negligible and no correction is required for the superallowed Fermi branching ratio.

Table I. Branching ratios, R, to 1^+ states in the β decay of ^{34}Ar (upper half) and ^{38}Ca (lower half) from experiment, ENSDF, and from shell-model calculations with USD (upper half) and Millener-Kurath (MK) (lower half) effective interactions.

ENSDF			USD		USD-A		USD-B	
E_x	R(%)	State	E_x	R(%)	E_x	R(%)	E_x	R(%)
0.46	0.91	$1^+; T = 0$	0.32	0.28	0.55	0.47	0.33	0.26
0.67	2.49	$1^+; T = 0$	0.66	2.24	0.27	2.09	0.52	0.42
2.58	0.86	$1^+; T = 0$	2.52	0.69	2.26	0.92	2.37	0.28
3.13	1.30	$1^+; T = 0$	3.25	0.85	3.15	0.93	3.05	0.90
		$1^+; T = 0$	3.88	0.0003	4.06	0.0022	3.73	0.0010
		$1^+; T = 1$	3.95	0.0017	3.69	0.0028	3.80	0.0015
		$1^+; T = 0$	4.98	0.0008	4.83	0.0015	4.88	0.0008
		$1^+; T = 0$	5.11	0.0005	5.17	0.0000	5.02	0.0006
feeding to states above 3.5 MeV				0.0032		0.0065		0.0039
feeding unobserved				0.0025		0.0052		0.0032

ENSDF			MK	
E_x	R(%	State	E_x	R(%)
0.46	2.81	$1^+; T = 0$	0.47	3.94
1.70	20.00	$1^+; T = 0$	1.26	15.70
3.34	0.50	$1^+; T = 0$		
3.86	0.50	$1^+; T = 0$	3.79	0.01
3.98	0.12	$1^+; T = 0$	4.08	0.04
		$1^+; T = 1$	4.78	0.0000
		$1^+; T = 0$	5.71	0.0002
		$1^+; T = 0$	5.80	0.0000
feeding to states above 4 MeV				0.0002

[1] V.E. Iacob *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2013-2014), p. I-20.

[2] H.I. Park *et al.*, Phys. Rev. C (to be published).

[3] B.H. Wildenthal, Prog. Part. Nucl. Phys. **11**, 5 (1984).

[4] B.A. Brown and W.A. Richter, Phys. Rev. C **74**, 034315 (2006).

[5] Evaluated Nuclear Structure Data File (ENDSF), [www.nndc.bnl.gov].

[6] D. Millener and D. Kurath, Nucl. Phys. **A283**, 315 (1975).