Eur. Phys. J. A **25**, s01, 97–98 (2005)
DOI: 10.1140/epjad/i2005-06-049-5

EPJ A direct
electronic only

Beta decays of ^{8}He, ^{9}Li, and ^{9}C

D.J. Millener[a]

Brookhaven National Laboratory, Upton, NY 11973, USA

Received: 23 October 2004 /

Abstract. The beta decays of ^{8}He, ^{9}Li, and ^{9}C are interpreted in terms of shell-model calculations in a p-shell basis. Particular attention is paid to the observed low-energy decays that exhibit large B(GT) values.

PACS. 23.40.-s β decay; double β decay; electron and muon capture – 21.60.Cs Shell model – 27.20.+n $6 \leq A \leq 19$

1 Introduction

Supermultiplet symmetry is essentially conserved by the central part of the p-shell Hamiltonian and is broken mainly by the spin-orbit interaction. Apart from terms involving n and n^2 the SU_4 invariant terms of a typical interaction look like [1]

$$H \sim -3.91 \sum_{ij} P_{ij} + 0.59L^2 - 1.08S^2 + 0.59T^2 \,.$$

Thus the central interaction favors low T and high S for states with the same spatial symmetry $[f]$. This opens up the possibility of low-energy Gamow-Teller (GT) transitions with large Gamow-Teller matrix elements (no change in spatial quantum numbers).

2 ^{8}He decay

The situation for ^{8}He(β^-)^{8}Li is shown in fig. 1. From table 1, the first three states have mainly [31] symmetry — the mixture of ^1P, ^3P, and ^3D varies considerably for different interactions— and owe their GT strength to small admixtures of [22] symmetry. On the other hand, the large B(GT) value, defined by $ft\,.\,B(\mathrm{GT}) = 6144.4$ s, for the 1_4^+ state is due to the match of spatial quantum numbers with the ^{8}He ground state and does not vary much in different calculations. The 1_4^+ state takes a large fraction of the Ikeda sum rule $12(g_A^{\mathrm{eff}})^2 \sim 14$, where $g_A^{\mathrm{eff}} \sim 1.07$ [2]. The $\sim$ 9.3 MeV state can decay by neutron emission ($S_n = 2.03$ MeV) and triton emission ($S_t = 5.39$ MeV), mainly through the [31] component. The shell-model spectroscopic factors lead to comparable neutron and triton widths and a total width of $\sim$ 1 MeV. Details are given in table 2. Existing fits [3,4,5] give $E_x \sim 9.0 \to 9.7$ MeV

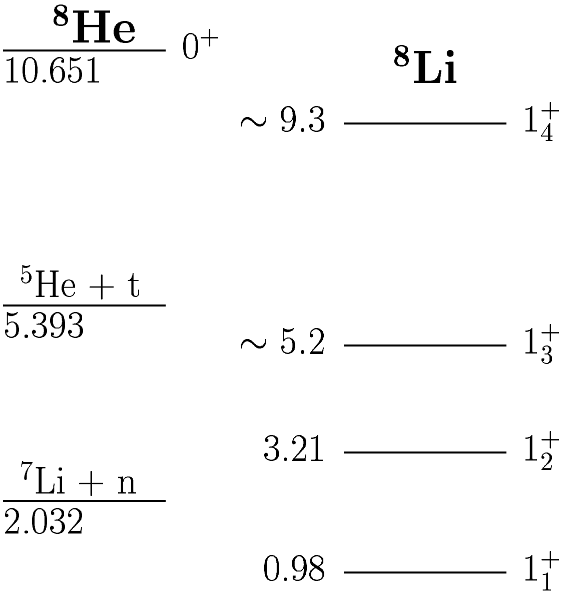

Fig. 1. Level spectrum showing the four 1^+ levels of ^{8}Li reached in the β^- decay of ^{8}He. Energies are in MeV.

Table 1. Symmetry content and B(GT) values for the 1^+ final states of ^{8}Li (see fig. 1) in the β^- decay of ^{8}He. The ^{8}He initial state is 74% [22] symmetry with $L = 0$ and $S = 0$ (26% [211] symmetry with $L = 1$ and $S = 1$). The 84(1)% branch to 1_1^+ combined with $t_{1/2} = 119.0(15)$ ms gives $B(\mathrm{GT}) = 0.391(7)$.

J_n^π	% [31]	% [22]	B(GT)
1_1^+	93.6	2.3	0.32
1_2^+	91.0	8.3	0.71
1_3^+	92.2	2.8	0.37
1_4^+	10.6	71.5	11.7

---

[a] Conference presenter. e-mail: `millener@bnl.gov`

Table 2. Calculated triton and neutron widths for the 1_4^+ state of ^{8}Li. The S values are the shell-model spectroscopic factors. The widths are estimated by matching R-matrix observed widths to single-particle widths from Woods-Saxon wells [1] and include integration over two-level R-matrix profile functions [6] for the broad ^{5}He final states.

Decay	S	Γ (keV)
$1_4^+ \xrightarrow{t} {}^5\mathrm{He}(3/2^-)$	0.030	254
$\xrightarrow{t} {}^5\mathrm{He}(1/2^-)$	0.066	253
$\xrightarrow{n} {}^7\mathrm{Li}(3/2^-)$	0.041	316
$\xrightarrow{n} {}^7\mathrm{Li}(1/2^-)$	0.018	129

and $B(\mathrm{GT}) = 5 \to 8$ for the 1_4^+ level but include only the ground-state triton channel and sometimes omit neutron channels [3]; see also [5]. Triton emission to the $1/2^-$ state of ^{5}He needs to be included in a new many-level, many-channel R-matrix analysis along the lines of ref. [4] but including averaging over the profiles of the ^{5}He states.

3 ^{9}Li and ^{9}C decay

A comparison of these mirror decays, based on analyses of experimental data, is shown in table 3. The initial states have mainly [32] symmetry with $L = 1$ and $S = 1/2$ (78%). Therefore, large $B(\mathrm{GT})$'s can occur for final states with [32] symmetry and $L = 1$ with $S = 1/2$ or $S = 3/2$, giving rise to five possible final states in the limit of good supermultiplet symmetry. The properties of the five corresponding shell-model states are given in table 4.

It should be noted that all final states except for the ^{9}Be ground state decay into the $\alpha + \alpha + N$ channel, in many cases by nucleon emission through the broad first-excited state of ^{8}Be or via α emission through the unbound states of ^{5}He or ^{5}Li (or perhaps by three-body breakup) making for a difficult analysis. The mirror transitions to low-lying states with dominant [41] symmetry have small $B(\mathrm{GT})$ values and are in quite good agreement. However, there is a large asymmetry for decays to $5/2^-$ levels near $E_x = 12$ MeV. This is unexpected for states with large $B(\mathrm{GT})$ values. The $B(\mathrm{GT})$ value for the decay of ^{9}C to the 12.19 MeV state of ^{9}B is consistent with the theoretical prediction in table 4. Suspicion falls on the very large $B(\mathrm{GT})$ value for the 11.81 MeV state of ^{9}Li because, in the limit of good supermultiplet symmetry, the $5/2^-$ state takes only 1/3 of the Ikeda sum rule $= 9(g_A^{\mathrm{eff}})^2 \sim 10.4$.

The previously known [32] symmetry states with $T = 1/2$ are the $7/2_2^-$ and $5/2_4^-$ states, both with dominant $L = 2$, $S = 3/2$ components. These states are strongly populated in pickup and knockout reactions on ^{10}B. The observed energies [7] are 11.81 and 14.48 MeV in ^{9}Be and 11.65 and 14.7 MeV in ^{9}B. The energies are well reproduced by the shell-model calculation. Table 4 show the $1/2^-$, $3/2^-$, and $5/2^-$ states that are predicted to have large $B(\mathrm{GT})$ values. As already noted, the energy and $B(\mathrm{GT})$ value for the $5/2_3^-$ state can account for the properies of the 12.19 MeV level observed in $^9\mathrm{C}(\beta^+)$. However, an explanation of the 9.0(10)% p_0 decay branch via f-wave emission lies beyond the scope of a p-shell calculation. Beta-decay strength is also predicted to a number of $1/2^-$ and $3/2^-$ states. If these states mainly decay by α emission, as suggested by the calculation, their effect on the measured alpha spectra may be difficult to see.

Table 3. Experimental data on the decays of ^{9}C and ^{9}Li [7]. The data for $^9\mathrm{C}(\beta^+)$ are from [8] after normalization to the ground-state branch of 54.1(15)% from [9]; also $B(\mathrm{GT}) = 1.92(24)$ for the 12.19 MeV level [9]. For $^9\mathrm{Li}(\beta^-)$ decay see [2, 10]; also $B(\mathrm{GT}) = 8.5(1.5)$ for the 11.81 MeV level [11].

	^{9}B	$^9\mathrm{C}(\beta^+)$	^{9}Be	$^9\mathrm{Li}(\beta^-)$
J^π	E_x	$B(\mathrm{GT})$	E_x	$B(\mathrm{GT})$
$3/2_1^-$	0	0.0295(8)	0	0.0292(9)
$5/2_1^-$	2.36	0.053(12)	2.43	0.046(5)
$1/2_1^-$	2.75	0.013(2)	2.78	0.011(5)
			11.28	1.4(5)
$5/2_3^-$	12.19	2.16(22)	11.81	8.9(1.9)
	14.0	0.36(5)		
$3/2^-;3/2$	14.65	~ 0	14.39	

Table 4. Results from a typical shell-model calculation. The first line gives the total [32] symmetry content for each shell-model eigenstate. The second line gives the dominant component, all with $L = 1$. The energies are given relative the $7/2_2^-$ state (83.4% [32] $L = 2$ $S = 3/2$) at 11.65 MeV in ^{9}B (see text). The $B(\mathrm{GT})$'s are given for $g_A^{\mathrm{eff}} = 1$.

	$1/2_2^-$	$3/2_3^-$	$5/2_3^-$	$1/2_3^-$	$3/2_4^-$
%[32]	89.8	97.2	88.1	89.5	89.2
%(S)	87(3/2)	86(3/2)	84(3/2)	83(1/2)	54(1/2)
$E_x(^9\mathrm{B})$	10.61	10.67	12.10	14.07	14.48
$B(\mathrm{GT})$	0.29	1.45	2.46	1.53	1.22

A multi-level, multi-channel R-matrix analysis of the the β-delayed particle decay of ^{9}C has been attempted [12]. An analysis that makes use of shell-model input, preferably from an extended basis (at least $(0+2)\hbar\omega$) shell-model calculation, would seem to be indicated.

This work is supported by the US Department of Energy under Contract No. DE-AC02-98CH10886.

References

1. D.J. Millener, Nucl. Phys. A **693**, 394 (2001).
2. W.-T. Chou *et al.*, Phys. Rev. C **47**, 163 (1993).
3. M.J.G. Borge *et al.*, Nucl. Phys. A **560**, 664 (1993).
4. F.C. Barker, E.K. Warburton, Nucl. Phys. A **487**, 269 (1988).
5. F.C. Barker, Nucl. Phys. A **609**, 38 (1996).
6. C.L. Woods *et al.*, Aust. J. Phys. **41**, 525 (1988).
7. D.R. Tilley *et al.*, Nucl. Phys. A **745**, 155 (2004).
8. E. Gete *et al.*, Phys. Rev. C **61**, 064310 (2000).
9. U.C. Bergmann *et al.*, Nucl. Phys. A **692**, 247 (2001).
10. G. Nyman *et al.*, Nucl. Phys. A **510**, 189 (1990).
11. Y. Prezado et al., Phys. Lett. B **576**, 55 (2003).
12. L. Buchmann *et al.*, Phys. Rev. C **63**, 034303 (2001).