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Competing $1n$ and $2n$ decays in ^{12}Be

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I have estimated widths for $2n$ decay for all positive-parity states expected in the region of 4.0–5.5 MeV in ^{12}Be. Results indicate that $2n$ decay could compete with $1n$ decay for one of the states—the fourth 2^+ that is likely to be the state observed in one-proton removal from ^{13}B.

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In one-proton removal from ^{13}B, Smith *et al.* [1] observed a state (or states) in ^{12}Be that decayed to the $1/2^+$ ground state (g.s.) and/or $1/2^-$ first excited state of ^{11}Be with a centroid decay energy of $E_n = 1.243(21)$ MeV and an extracted width of 634(60) keV. After considering all the possible J^π values, Smith *et al.* [1] preferred 2^-. Elsewhere [2,3], I have explained my reasons for preferring 2^+ (or possibly 0^+). I estimated the $1n$ decay widths to be expected for various states that might lie in this region of excitation [3]. At that time, I expressed the opinion that $2n$ decay should be quite small. Smith *et al.* [1] had set an upper limit on possible $2n$ decays of 5%. I have now performed simple calculations to estimate the relevant $2n$ decay widths.

Wave functions of the first two theoretical $(sd)^2$ 2^+ states of ^{12}Be are listed in Table I. The $L = 2$ $2n$ cluster spectroscopic factors are given in the last column. For the first of these two states, S_{2n} is 0.57, and it is 0.0037 for the second. If small amplitudes involving the $d_{3/2}$ orbital had been included, S for the first state would have been closer to unity, but the value listed is sufficient for the present purposes.

Results of the ^{10}Be(t, p) reaction [4,5] indicated that the lowest 2^+ state at 2.1 MeV contains about 80% of the first $(sd)^2$ 2^+ state and about 20% of the pure p-shell 2^+. The 2^+ that has the orthogonal linear combination is labeled $2_4{}^+$ and is one of the three 2^+ states that should lie in the region near $E_n = 1.3$ MeV [3]. Wave functions of these two states are listed in Table II. All such positive-parity states and their dominant configurations are listed in Table III. For the pure p-shell 2^+ state, Cohen-Kurath [6] list $S = 0.023$ (their DMAG).

I have computed $2n$ single-particle (sp) widths in a Woods-Saxon potential well having r_0, $a = 1.37$, 0.70 fm, using a mass-2, charge-0 cluster. For definiteness, I assumed a $2n$ decay energy of 0.70 MeV. If such decays are observed at a different energy, it is a simple matter to re-do the calculations. Relevant decays are depicted in Fig. 1.

I discuss 2^+ states first. The sp widths for $(sd)^2$ and p-shell 2^+ states are different. For a wide range of energies, $\Gamma_{sp}(q = 4)/\Gamma_{sp}$ is about 1.7 for $L = 2$. [Here, q is the number of oscillator quanta.] For the various 2^+ states in Table III, I have computed Γ_{calc} $(q = 4)$ and Γ_{calc} $(q = 2)$ separately, where $\Gamma_{calc} = S\Gamma_{sp}$. These amplitudes for $(sd)^2$ and p-shell decay should be added coherently. Therefore, whenever both are present, I have summed the square roots of the $q = 4$ and $q = 2$ calculated widths with the appropriate sign. For the state labeled $2_4{}^+$, the two amplitudes have opposite signs. Table IV lists the previous estimated $1n$ decay widths [3] and the present predicted $2n$ widths. Because this width for $2_4{}^+$ involves destructive interference between the $q = 2$ and the 4 amplitudes, a small change in either can cause a larger change in the final predicted width. In any case, it can be noted that $2n$ decay of the $2_4{}^+$ state is not negligible and should be observable.

For $L = 0$, the absence of a barrier is a complication. In such cases, the sp width varies as $E^{1/2}$. In the present example for $L = 0$ with both Γ and E in units of MeV, I have used $\Gamma_{sp}(q = 2) = E^{1/2}$ and $\Gamma_{sp}(q = 4) = (3E)^{1/2}$. This gives the same $(q = 4)/(q = 2)$ ratio as was obtained for $L = 2$. These results are also listed in Tables III and IV. The $L = 0$ numbers are less reliable than those for $L = 2$.

My calculated total width for the $2_4{}^+$ state is 128 keV–115 keV for $1n$ decay and 13 keV for $2n$ decay. The width reported by Smith *et al.* [1] was 634(60) keV, which is significantly larger. Note that my predictions are that the $1n$ decay goes to both the g.s. and the $1/2^-$ state of ^{11}Be, providing two peaks separated by 0.32 MeV, each with a width of 128 keV. Also, any $2n$ decays will result in a spread of neutron energies in a

TABLE I. Wave functions of first two theoretical $(sd)^2$ 2^+ states in ^{12}Be.

State	ds	dd	$S_{2n}(L = 2)$
$(sd)^2$ $2_1{}^+$	0.934	0.358	0.57
$(sd)^2$ $2_2{}^+$	− 0.358	0.934	0.0037

TABLE II. Wave functions of first and fourth 2^+ states in ^{12}Be.

State	Wave function
$2_1{}^+$	$0.894\ (sd)^2 2_1{}^+ + 0.447$ p-shell 2^+
$2_4{}^+$	$-0.447\ (sd)^2\ 2_1{}^+ + 0.894$ p-shell 2^+

TABLE III. Positive-parity states expected in the range of $E_x = 4$–5.5 MeV [3] in ^{12}Be and their $2n$ decay properties. (Widths are in keV.)

J^π	Dominant configuration	$q = 4$			$q = 2$		
		S	Γ_{sp}	Γ_{calc}	S	Γ_{sp}	Γ_{calc}
0_3^+	Second ^{10}Be(g.s.) $\times (sd)^2 0^+$	0.014	1450	20	0	835	0
0_4^+	^{10}Be(2^+) $\times (sd)^2 2^+$	0	1450	0	0	835	0
2_2^+	^{10}Be(2^+) $\times (sd)^2_0$	0	225	0	0	130	0
2_3^+	Second ^{10}Be(g.s.) $\times (sd)^2\, 2^+$	0.0037	225	0.8	0	130	0
2_4^+	^{12}Be p-shell 2^+	0.2×0.57	225	26	0.8×0.023	130	2.4

singles spectrum. Additionally, some other 0^+ and 2^+ states may be present at some level, thereby broadening the peak. Finally, I have suggested elsewhere [7] that several neutron widths obtained in decay-in-flight experiments appear to be too large by a factor of about 1.6. Determination of the width of this state in a better resolution experiment could be very revealing.

I noted above that Smith *et al.* [1] reported a limit of less than 5% for $2n$ decay. My prediction is about 11% with some uncertainty. Any other states in the region are predicted to have much smaller $2n$ decays so that, if they are present, the total $2n/1n$ ratio would be smaller. I note that 5% of the width of Smith *et al.* [1] is 32(3) keV, substantially greater than my predicted $2n$ decay width of 13 keV.

To summarize, using a simple $2n$ cluster model, I have estimated widths for $2n$ decay for all positive-parity states expected in the region of 4.0–5.5 MeV in ^{12}Be. Perhaps surprisingly, results indicate that $2n$ decay could compete with $1n$ decay for the fourth 2^+ state—the one that is likely to be the state observed in one-proton removal from ^{13}B.

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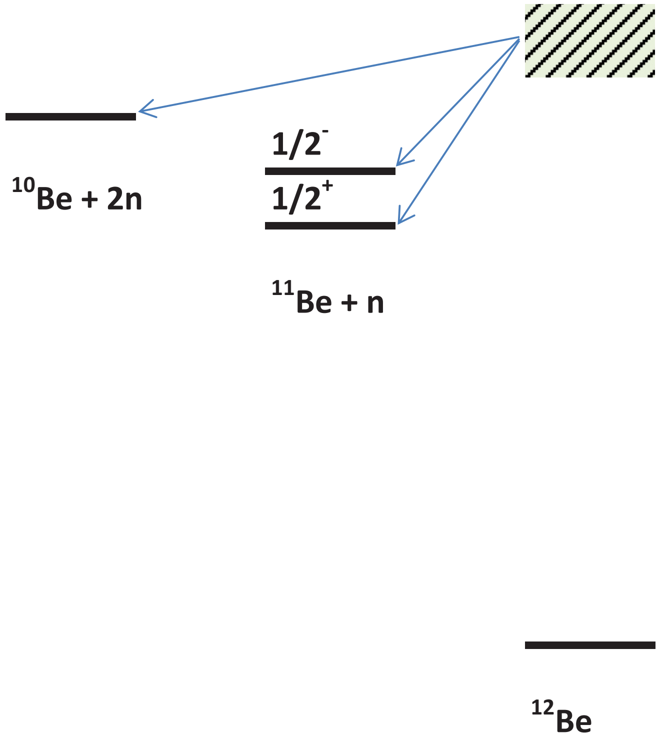

FIG. 1. Location of the $E_n = 1.24$-MeV state in ^{12}Be and its relevant decays.

TABLE IV. Estimated $1n$ and $2n$ decay widths (keV) for states listed in Table III.

J^π	Γ_{1n}		Γ_{2n}	Γ_{2n}/Γ_{1n}
	$1/2^+$	$1/2^-$		
0_3^+	(381)	~ 64	(20)	(0.04)
0_4^+	(295)	~ 32	0	0
2_2^+	3	0	0	0
2_3^+	26	32	0.8	0.014
2_4^+	35	80	13	0.11

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