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Neutron decays of ^{13}Be* to the 0_2^+ state of ^{12}Be

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We suggest that an appreciable portion of the $1/2^-$ peak in a recent $^{13}\mathrm{Be}^* \to {}^{12}\mathrm{Be} + n$ experiment is actually due to $5/2^+$ decays to the excited 0^+ state.

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I. INTRODUCTION

A recent paper [1] studied the reaction ^{1}H(^{14}Be, ^{13}Be*) and detected the outgoing ^{13}Be* as $^{12}\mathrm{Be} + n$ coincidences, gating on the absence of a fast γ ray in ^{12}Be of energy 2.1(2^+) or 2.7(1^-) MeV. They observed a peak at a $^{12}\mathrm{Be} + n$ relative energy of $E_n = 0.51$ MeV with a width of 0.45 MeV (after correcting for experimental resolution). They identify this peak as a $1/2^-$ state expected in this region. (The history is well summarized in Ref. [1].) They quote a single-particle (sp) $l = 1$ width of 0.55 MeV for a resonance at this energy, implying a spectroscopic factor of 0.82.

II. THE 1/2⁻ STATE

In any reasonable model of ^{12}Be, the ground state (g.s.) is written, in an obvious notation, as

$$^{12}\mathrm{Be(g.s.)} = A\left[{}^{10}\mathrm{Be_{CK}(g.s.)\,(sd)^2}\right] + B\left[{}^{12}\mathrm{Be_{CK}(g.s.)}\right],$$

where the subscript CK (for Ref. [2]) is used to denote pure p-shell structures. Various models give different values of A, B, but most would have $A \geqslant B$. Our favorite wave function [3] has $A^2 = 0.68$, $B^2 = 0.32$. The g.s. could contain a component of $^{10}\mathrm{Be_{CK}}$ (2^+) (sd) $^{2}_{2+}$, but it should be small, and we ignore it here. In our model, the excited 0^+ state is

$$^{12}\mathrm{Be}(0_2^+) = -\,B\left[{}^{10}\mathrm{Be_{CK}\,(g.s.)\,(sd)^2}\right] + A\left[{}^{12}\mathrm{Be_{CK}(g.s.)}\right].$$

The first $1/2^-$ state of ^{13}Be is mostly

$$\gamma\left[{}^{11}\mathrm{Be_{CK}}(1/2^-)\,(\mathrm{sd})^2_{01}\right] + \delta\left[{}^{9}\mathrm{Be_{CK}}(1/2^-)\,(\mathrm{sd})^4_{02}\right] + \varepsilon\left[{}^{9}\mathrm{Be_{CK}}(3/2^-)\,(\mathrm{sd})^4_{22}\right].$$

where the double subscripts denote JT, where T is isospin. We expect the last two terms to be small. The spectroscopic factor for decay of this $1/2^-$ state to the g.s. of ^{12}Be by n emission is

$$S[{}^{13}\mathrm{Be}(1/2^-) \to {}^{12}\mathrm{Be(g.s.)} + n] = A^2\,\gamma^2 S[{}^{11}\mathrm{Be}(1/2^-) \to {}^{10}\mathrm{Be(g.s.)} + n].$$

The latter factor has the value [2] 0.60. Even with our large value of A^2, and even if γ^2 is near unity, the limit on the expected value of S is thus $S \leqslant 0.40$, compared to 0.82 in Ref. [1]. Furthermore, our calculated sp width, in a Woods-Saxon well with r_0, a = 1.25, 0.65 fm, is $\Gamma_{\rm sp} = 0.40$ MeV, implying $S = 1.1$ [1]. The authors do state that if they analyze the upper part of their energy range differently (two d states rather than one), the experimental $1/2^-$ width changes by 0.13 MeV. Even then, S would be 0.85 (with our sp width)—still more than twice the expected value. (See Table I.) Thus we conclude that a large portion of their $1/2^-$ peak must contain another contribution that has another origin, which we now discuss.

III. THE 5/2⁺ STATES

The first $5/2^+$ state of ^{13}Be should be

$$^{13}\mathrm{Be}(5/2_1^+) = \alpha\left[{}^{12}\mathrm{Be_{CK}(g.s.)} \times 1d5/2\right] + \beta\left[{}^{10}\mathrm{Be_{CK}(g.s.)}\ (\mathrm{sd})^3_{5/2}\right].$$

Another competing component is ^{12}Be(2^+)$2s1/2$, which could be appreciable, but we omit it here because we want to keep things simple and because this component has no direct n decay to the 0^+ states of ^{12}Be. We return to this point later. In a two-state model, the next $5/2^+$ state would be

$$^{13}\mathrm{Be}(5/2_2^+) = -\beta\left[{}^{12}\mathrm{Be_{CK}(g.s.)} \times 1d5/2\right] + \alpha\left[{}^{10}\mathrm{Be_{CK}(g.s.)}\ (\mathrm{sd})^3_{5/2}\right].$$

In both cases, the (sd)^3 configuration is primarily a combination of $s_0^2\,d$ and d^3. In the simplest two-state model for the 0^+ and 2^+ states, we would expect β^2/α^2 to be about 2 (actually near 0.68/0.32; see earlier). Mixing of the $2^+ \times 2s1/2$ component into these two $5/2^+$ states would reduce both β and α but should not drastically alter the ratio.

We have computed the decays of this second $5/2^+$ state to the g.s. of ^{12}Be and to the excited 0_2^+ state at 2.24 MeV. We find that for a wide range of values of β/α, the decay to

TABLE I. Properties of $1/2^-$ resonance in ^{13}Be (energies and widths in MeV).

E_n	$\Gamma_{\rm exp}$[a]	$\Gamma_{\rm sp}$	$S = \Gamma_{\rm exp}/\Gamma_{\rm sp}$
0.51	0.45	0.55[b]	0.82
		0.40[c]	1.1
0.49[d]	0.32[d]	0.38[c]	0.84
Theory[e]			$\leqslant$ 0.41

[a] Reference [1], after correcting for experimental resolution.
[b] Quoted in Ref. [1].
[c] Our value.
[d] Alternative analysis in Ref. [1].
[e] $S = A^2\gamma^2 S[{}^{11}\mathrm{Be_{CK}}(1/2^-) \to {}^{10}\mathrm{Be_{CK}} + n]$ (see text).

0_2^+ is highly favored, even with the limited phase space. For $1 < \beta^2/\alpha^2 < 4$, the BR is less than unity. We propose that this $5/2_2^+$ state is near $E_n = 2.8$ MeV so that decay to the 0_2^+ state would contribute to the 0.51 MeV peak. One of the analyses in Ref. [1] had a second *d* state at about 2.9 MeV. In our calculations, the sp width for $l = 2$ is 34 keV for $E_n = 0.51$ MeV and 1.1 MeV for $E_n = 2.8$ MeV. Thus, from phase space, the g.s. decay branch is favored by more than a factor of 30. But the structure goes very heavily in the other direction. In Fig. 1, we plot the ratio $S\Gamma_{\rm sp}/S'\Gamma'_{\rm sp}$, where S and $\Gamma_{\rm sp}$ refer to the decay of the second $5/2^+$ state to the g.s., and S' and $\Gamma'_{\rm sp}$ refer to the 0_2^+ state. The S's are computed from the wave functions given earlier. Note that for a very wide variation in the wave function, the 0_2^+ decay is favored. Other components in the wave functions will undoubtedly fill in the minimum somewhat, but the principal feature should remain. The experimental setup in Ref. [1] could not rule out decays to 0_2^+ because of its long mean life; rather they argued that the 0.5 MeV peak could not be due to decays of a ~2.7 MeV state to 0_2^+ because such decays should be accompanied by much stronger (on penetrability grounds) decays to the g.s.. If we are correct and the $5/2^+$ states have the structure suggested here, these g.s. decays are severely inhibited, and their argument is therefore not valid.

The width of a peak arising from these proposed decays to 0_2^+ would be nearly all resolution width. For the proposed decays to the excited 0^+ state to cause a widening of the 0.5 MeV peak, their energy should be slightly different from the energy of the *p*-wave resonance. If so, it might be possible to observe different momentum distributions for the left and right halves of the 0.5 MeV peak in the data of Ref. [1]. The decays suggested here should have a *d*-wave momentum distribution.

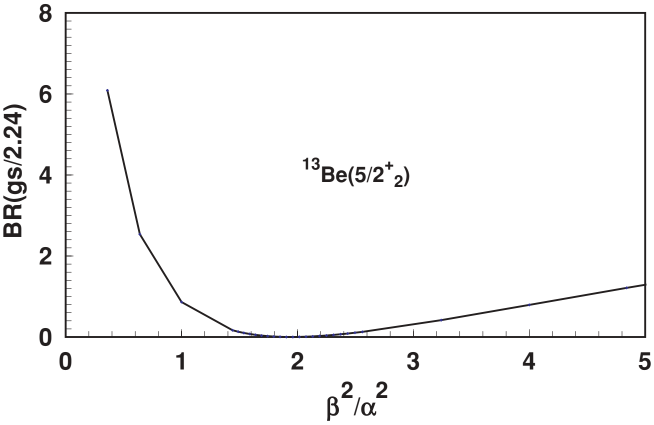

FIG. 1. For the second $5/2^+$ state of ^{13}Be, the ratio of widths for decay to the g.s. and excited 0^+ state is plotted vs β^2/α^2, the ratio of sp to (sd)^3 in the $5/2^+$ state.

There is also the question of forming these $5/2^+$ states from ^{14}Be. With a reasonable wave function of ^{14}Be(g.s.), we expect that the $5/2_2^+$ state will have about 50%–70% of the strength of $5/2_1^+$ in the breakup of ^{14}Be(g.s.).

We think it would be very interesting to look for decays of ^{13}Be* to the excited 0^+ state of ^{12}Be.

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