Proton removal from ^{13}B to negative-parity states of ^{12}Be

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I have estimated the amount of p-shell $\rightarrow (sd)^2$ core excitation in ^{13}B that involves an sd-shell proton, and then the spectroscopic factors for proton removal from ^{13}B to negative-parity states of ^{12}Be. Results are $S \sim 10^{-2}$, indicating that these states are unlikely to be populated in that reaction.

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I. INTRODUCTION

The dominant structure of all the low-lying negative-parity states of ^{12}Be consists of a ^{11}Be $1/2^-$ or $3/2^-$ core coupled to s or d neutron. (Here, s refers to $2s_{1/2}$, and d to $1d_{5/2}$.) The known 1^- state at 2.7 MeV [1] and the probable 3^- state [2,3] at 4.58 MeV are very well described [3,4] as ^{11}Be$(1/2^-) \otimes s$ and d, respectively. The observed width of 107(17) keV [5] for the 3^- state corresponds to near unit spectroscopic factor [6] for 3^- to $1/2^-$ $1d_{5/2}$ decay. The accompanying 0^- and 2^- states [4] have not been identified.

The next set of negative-parity states would consist of s or d neutron coupled to the $3/2^-$ state of ^{11}Be at $E_x = 2.65$ MeV [7,8]. This coupling gives rise to 1^- and 2^- for s, and 1^-–4^- for d. Some mixing between the two configurations (and the one above) could occur. Configurations involving $1d_{3/2}$ or three nucleons in the sd shell will occur at much higher excitation energy, and I will ignore them here. My aim is to estimate the expected strengths of these negative-parity states in proton removal from ^{13}B.

For states at low excitation in ^{12}Be, components with a $1s_{1/2}$ proton hole are extremely small. Thus, to populate any of these negative-parity states, parity conservation requires proton removal from the $2s1d$ shell. For the ground state (g.s.) of ^{13}B, excitations involving sd-shell *neutrons* have been estimated to be about 30(2) [9] or 25(5)% [10]. [I interpreted a p-shell component of 0.70–0.80 to mean 0.75(5), and hence 0.25(5) for the $(sd)^2$ component.] However, in lowest order, it contains no sd-shell *protons*. I estimate this impurity here.

II. MODEL AND CALCULATIONS

To have a nonzero overlap with these negative-parity states, the ^{13}B impurity must contain an sd-shell neutron. As outlined above, it must also contain an sd-shell proton (the proton that is removed). Thus, the sd-shell pair is pn. The conservation of angular momentum requires the total J of the impurity configuration to be 3/2. The most likely such structure is ^{11}Be$(1/2^-) \otimes (sd)^2_{10}$, where the double subscripts denote JT of the sd-shell pair. Thus, I write

$$^{13}\mathrm{B(g.s.)} = \mathrm{A}\,^{11}\mathrm{B}_{1p}\mathrm{(g.s.)} \otimes \nu(sd)^2 + \mathrm{B}\,^{13}\mathrm{B}_{1p}\mathrm{(g.s.)} + \varepsilon\,^{11}\mathrm{Be}(1/2^-) \otimes (sd)^2_{10},$$

and I attempt to estimate ε.

In weak-coupling parlance, this core-excited configuration has the structure ^{11}Be$(1/2^-) \otimes {}^{18}$F(g.s.). Its unperturbed energy can be estimated by using the weak-coupling expressions of Banzal-French-Zamick (BFZ) [11,12]:

$$^{11}\mathrm{Be}(1/2^-) \otimes {}^{18}\mathrm{F(g.s.)} = {}^{11}\mathrm{Be}(1/2^-) + {}^{18}\mathrm{F(g.s.)} – {}^{16}\mathrm{O} + 10a + 4c,$$

where a is the particle-hole (ph) interaction, and c is the Coulomb ph term. The nuclide symbols refer to the mass excesses of those nuclei [13]. To get the excitation energy of this state in ^{13}B, I simply subtract the g.s. mass excess of ^{13}B. If I use standard values of the parameters, $a = 0.43$, $c = –0.30$, both in MeV, the result is $E_x = 12.7$ MeV. I can estimate the magnitude of this component in the physical ^{13}B(g.s.) with first-order perturbation. In first-order perturbation, the mixing amplitude is given by $\varepsilon = V/\Delta E$, where V is the potential responsible for the mixing, and ΔE is the energy difference. Even if the mixing matrix element between this core-excited configuration and the $1p$-shell g.s. is as large as 2 MeV, the resulting wave-function amplitude ε is 0.16, i.e., about 0.026 in intensity. This estimate is likely to be an upper limit.

To obtain the spectroscopic factor from this component of ^{13}B(g.s.) $\rightarrow$ ^{12}Be(1^-), I need to know the amount of s^2 in $(sd)^2_{10}$:

$$(sd)^2_{10} = a\,d^2 + b\,s^2 + c\,dd' + \dots,$$

where d' stands for $1d_{3/2}$. In a standard sd-shell calculation, b^2 is about 0.25 [14]. Thus, the expected spectroscopic factor for ^{13}B(g.s.) $\rightarrow$ ^{12}Be(1^-) is $S = b^2\varepsilon^2 \sim 6.4 \times 10^{-3}$, with an estimated uncertainty of about a factor of two. (In general, computing these spectroscopic factors involves uncoupling and recoupling angular momenta, with the aid of $6j$ coefficients. In this first example, the relevant $6j$ coefficient is unity.) Results for the other low-lying negative-parity states of ^{12}Be will be similar. From the d^2 component of the $(sd)^2_{10}$ structure, the first 3^- and 2^- states of ^{12}Be can be reached in d proton removal. Squares of relevant recoupling coefficients are 2/3 for 3^- and 1/3 for 2^-. In a similar manner to that detailed above, resulting spectroscopic factors are as listed in Table I.

Another core excitation that could contribute involves $1/2^- \otimes (sd)^2_{21}$, but still with $T_z = 0$ for the sd-shell pair. [The configuration $1/2^- \otimes (sd)^2_{01}$ lies lower, but it has the wrong J

TABLE I. Estimated spectroscopic factors for proton removal from core-excited admixtures in ^{13}B to the lowest negative-parity states in ^{12}Be.

Impurity Configuration[a]	S for proton removal from ^{13}B to negative-parity states			
	ℓ	1^-	3^-	2^-
$^{11}\mathrm{Be}(1/2^-) \otimes (sd)^2_{10}$	0	0.0064	–	–
	2	–	0.0068	0.0032
$^{11}\mathrm{Be}(1/2^-) \otimes (sd)^2_{21}$	2	0.0048	0.008	0.016

[a]Double subscripts denote JT of the sd-shell pair.

to mix with ^{13}B(g.s.).] We can estimate the expected energy of this core-excited configuration again by using BFZ as above. However, here, caution is required. For core excitation involving more than one hole and more than one particle and un-stretched isospin (as here), the BFZ formula is well known to provide too low an excitation energy [15]. For this configuration, I need the isospin weak-coupling parameter, for which I use $b = 5.0$ MeV. The BFZ estimate of the excitation energy of the $1/2^- \otimes (sd)^2_{21}$ is thus about 10.8 MeV. Given the caveat above, this is a lower limit. The $(sd)^2_{21}$ state consists mostly of ds and d^2 components. Estimating spectroscopic factors as above, results are as given in Table I.

III. SUMMARY

It can be noted that none of these core excitations provide any significant proton removal strength from ^{13}B to negative-parity states of ^{12}Be. It is thus very likely that any states observed in this reaction will have positive parity. This expectation is supported by the fact that a recent proton-removal experiment [16] from ^{13}B saw no evidence for the probable 3^- state at 4.58 MeV. For comparison, the p-shell spectroscopic factor for $^{13}\mathrm{B} \to {}^{12}\mathrm{Be}(2^+)$ is about 2.6 [3,17]—several hundred times larger than for the negative-parity states. It thus appears reasonable that in proton removal from ^{13}B, virtually all of the observed strength will go to positive-parity states, and virtually none to negative-parity states.

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