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Estimate of ^{12}C × $(sd)^4$ impurity in ^{16}C(g.s.)

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Recent results for the β decay of ^{17}B, together with a simple model, allow an estimate of the $(sd)^4$ component in ^{16}C(g.s.). The result is about 0.02, a small number.

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I. INTRODUCTION

The ground state (g.s.) of ^{12}Be is well known to have a predominant component whose structure is two sd-shell neutrons coupled to a p-shell ^{10}Be(g.s.). This $^{10}\text{Be}_{1p}$(g.s.) $\times (sd)^2$ component is about 68% of the total g.s. wave function with most of the remainder being the normal p-shell ^{12}Be(g.s.). A recent summary [1] contains the relevant references. In ^{14}Be, the two dominant components are $^{12}\text{Be}_{1p}$(g.s.) $\times (sd)^2$ and $^{10}\text{Be}_{1p}$(g.s.) $\times (sd)^4$ with little firm information that concerns the two percentages [2]. In ^{14}C, the g.s. and a 0^+ state at 6.59 MeV are well described [3] in a two-state model, which consists of the normal p-shell ^{14}C(g.s.) and the structure $^{12}\text{C}_{1p}$(g.s.) $\times (sd)^2$. One estimate [3] has about 12% of the latter configuration in the physical g.s. I return to the case of ^{14}C below. The fact that the core excitation is so much larger in ^{12}Be than in ^{14}C is well understood as a consequence of the disappearance of the $N = 8$ gap in ^{12}Be [4–6]. For the same reason, one might expect more core excitation in ^{14}Be than in ^{16}C, but neither is currently known.

In ^{16}C, properties of many positive-parity states agree well [7] with those of states expected from the structure ^{14}C(g.s.) $\times (sd)^2$, which contains two 0^+, two 2^+, one 3^+, and one 4^+ state. Yet, various shell-model calculations [8,9] predict appreciable amounts of the configuration $^{12}\text{C}_{1p}$(g.s.) $\times (sd)^4$ in ^{16}C(g.s.). No experiment has yet been able to measure the magnitude of this component. Recent research, which concerns ^{17}C [10], has provided a possible means to estimate the amount of this component in ^{16}C, and that is the subject of the present paper.

II. ANALYSIS AND RESULTS

In β decay of ^{17}B, a $1/2^-$ state was observed [10] at an excitation energy of 2.71(2) MeV, 1.98 MeV above the $^{16}\text{C} + n$ threshold. The total width of this state was reported as 40(10) keV. In ^{17}C, the lowest negative-parity states are predominantly of the form $^{13}\text{C} \times (sd)^4$. The most direct route for such a $1/2^-$ state to decay to ^{16}C(g.s.) is for the decay to proceed to a $^{12}\text{C} \times (sd)^4$ component in ^{16}C(g.s.). If we write

$$^{16}\text{C (g.s.)} = a\,^{14}\text{C (g.s.)} \times (sd)^2 + b\,^{12}\text{C(g.s.)} \times (sd)^4, \quad \text{with} \quad a^2 + b^2 = 1,$$

then the spectroscopic factor S_{17} for the decay $^{17}\text{C}(1/2^-) \rightarrow {}^{16}$C(g.s.) is just b^2 times $S[^{13}\text{C(g.s.)} \rightarrow {}^{12}\text{C(g.s.)}]$. Cohen-Kurath [11] have $S_{13} = 0.61$ for the latter factor. We also have $S_{17} = \Gamma_{\text{exp}}/\Gamma_{\text{sp}}$. The relevant decay has $E_n = 1.98$ MeV for which the single-particle (sp) width is large enough to be difficult to calculate—but certainly in the range of 2–5 MeV. For the present purpose, I use $\Gamma_{\text{sp}} = 3.6$ MeV. Then, $S_{17} = \Gamma_{\text{exp}}/\Gamma_{\text{sp}} = 0.04/3.6 = 0.011$. Equating this value to $S_{13}\, b^2$ gives $b^2 = 0.011/0.61 = 0.018$ for the amount of $(sd)^4$ in ^{16}C(g.s.). This rough estimate for ^{17}C could probably be uncertain by as much as 50%–100% because of the difficulty of estimating the sp width. But, even so, the result is that this component in ^{16}C is quite small. With the estimated uncertainty, the final result is $b^2 = 0.018(14)$.

A similar analysis previously gave approximate agreement [12] with the measured neutron width of the first $1/2^-$ state in ^{15}C. In that case, the newest measurement of the $1/2^-$ width gave 29(3) keV, which resulted in a spectroscopic factor of $S_{15} = 0.023$ [12]. Then, applying the same analysis to ^{14}C as used above for ^{16}C leads to $b^2(^{14}\text{C}) = 0.038(19)$ where I have assigned a 50% uncertainty. The estimate of this quantity from an analysis of the $^{12}\text{C}(t,p)$ reaction was 0.12(3) [3]. The ratio of the two is 3.2(18), about 1.2σ from unity. One shell-model calculation [13] gave $b^2 \sim 0.08$. Analysis of results of the $^{14}\text{O}(p,t)$ reaction [14] (in reverse kinematics) led to a limit of $b^2 > 0.06$ [15] in the mirror nucleus ^{14}O. I recently suggested another experiment to measure this quantity in ^{14}C [15].

III. SUMMARY

Using a newly reported width for the lowest $1/2^-$ state of ^{17}C and a calculated single-particle width, I computed the relevant spectroscopic factor. Then, in a simple two-state model of ^{16}C(g.s.), the $(sd)^4$ component is estimated to be about 0.02 with a large uncertainty. It remains a challenge for open-core shell-model calculations to reproduce this small value.

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