Population of ^{11}O* in two-neutron removal from ^{13}O

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I have used a simple model to estimate the relative populations expected for the ground state (g.s.) and three excited states of ^{11}O in $2n$ removal from ^{13}O. Results are ratios exc./g.s. of at most a few percent for each excited state, compared to ratios near unity suggested in a recent experiment involving ^{11}O.

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I. INTRODUCTION

Recently, Webb *et al.* [1] produced ^{11}O with $2n$ removal from ^{13}O and observed it by detecting ^{9}C and $2p$ in coincidence. To reproduce the decay energy spectrum, they found that they needed four states—the ground state (g.s.) and three excited states, whose J$^\pi$ they took to be $5/2^+$, $3/2^-$, and $5/2^+$. Here, I attempt to estimate the relative population of these states in a simple model.

II. CALCULATIONS AND ANALYSIS

Throughout, I treat ^{11}O and ^{11}Li as mirrors, and likewise for ^{13}O/^{13}B and ^{11}B/^{11}C. The main components of the g.s. of ^{13}B are ^{13}B$_{1p}$ and ^{11}B$_{1p} \times \nu(\mathrm{sd})^2$, so that one may write

$$^{13}\mathrm{O(g.s.)} = \mathrm{A}\ ^{11}\mathrm{C}_{1p} \times \pi(\mathrm{sd})^2 + \mathrm{B}\ ^{13}\mathrm{O}_{1p},$$

where the subscripts $1p$ denote structures totally within the $1p$ shell. The best evidence for core excitation of the type $^{11}\mathrm{B} \times \nu(\mathrm{sd})^2$ in ^{13}B(g.s.) involves the observation [2] of the Gamow-Teller β decay of ^{14}Be(g.s.) to a 1^+ level at 1.28 MeV in ^{14}B, followed by emission of a neutron to the $3/2^-$ ^{13}B(g.s.). The measured neutron width of the ^{14}B level then allows an estimate of the ^{13}B(g.s.) configuration mixing. Details of the procedure are given elsewhere [2,3]. Results are listed in Table I, along with one other estimate [4]. Thus, for ^{13}B, estimates of A^2 range from 0.21 to 0.30 [2–4], with a "best" value of 0.21(2) [3].

The ^{11}Li(g.s.) has long been treated as a combination of ^{11}Li$_{1p}$ and ^{9}Li$_{1p} \times \nu(\mathrm{sd})^2$, so that one may use

$$^{11}\mathrm{O(g.s.)} = \mathrm{a}\ ^{9}\mathrm{C}_{1p} \times \pi(\mathrm{sd})^2 + \mathrm{b}\ ^{11}\mathrm{O}_{1p}.$$

In a two-state model, the excited $3/2^-$ state is just the orthonormal linear combination

$$^{11}\mathrm{O}(3/2^-\mathrm{exc}) = -\mathrm{b}\ ^{9}\mathrm{C}_{1p} \times \pi(\mathrm{sd})^2 + \mathrm{a}\ ^{11}\mathrm{O}_{1p}.$$

The latest estimate [5] of a^2 is $0.33^{+0.03}{}_{-0.05}$. Other values are similar [6,7]. Amplitudes for producing these two $3/2^-$ states in two-neutron removal from ^{13}O are thus

$$\boldsymbol{\mathcal{A}}(\mathrm{g.s.}) = \mathrm{Aa}\,\boldsymbol{\mathcal{A}}(^{11}\mathrm{C}_{1p} \rightarrow {}^{9}\mathrm{C}_{1p}) + \mathrm{Bb}\,\boldsymbol{\mathcal{A}}(^{13}\mathrm{O}_{1p} \rightarrow {}^{11}\mathrm{O}_{1p});$$

$$\boldsymbol{\mathcal{A}}(3/2^-\mathrm{exc}) = -\mathrm{bA}\,\boldsymbol{\mathcal{A}}(^{11}\mathrm{C}_{1p} \rightarrow {}^{9}\mathrm{C}_{1p}) + \mathrm{aB}\,\boldsymbol{\mathcal{A}}(^{13}\mathrm{O}_{1p} \rightarrow {}^{11}\mathrm{O}_{1p}).$$

Note that all transitions involve removal of a p-shell neutron pair, while the sd-shell protons act as spectators. Thus, the expected amplitude ratio is approximately

$$\boldsymbol{\mathcal{A}}(3/2^-\mathrm{exc.})/\boldsymbol{\mathcal{A}}(\mathrm{g.s.}) \sim (-\mathrm{bA} + \mathrm{aB})/(\mathrm{Aa} + \mathrm{Bb}) = 0.135,$$

with an estimated uncertainty of about 24%, or a predicted cross section ratio of about 0.02(1).

The lowest positive-parity state in ^{11}Li has the structure $^9\mathrm{Li}_{1p} \times \nu((1p_{1/2})(2s_{1/2}))_{1-}$. This configuration actually contains three states, with J$^\pi$ = $5/2^+$, $3/2^+$, and $1/2^+$. Thus, the configuration of this state in ^{11}O is $^9C_{1p} \times \pi((1p_{1/2})(2s_{1/2}))_{1-}$. This configuration in ^{11}O cannot be produced from the ^{13}O(g.s.) considered above. Rather, to make this configuration from ^{13}O by two-neutron removal requires an sd-shell neutron in its g.s. By correspondence with the mirror ^{13}B, the lowest such admixtures in ^{13}O(g.s.) would be $^{11}\mathrm{N}(1/2^-) \times (\mathrm{sd})^2{}_{10\ \mathrm{or}\ 21}$, where the subscripts denote JT of the sd-shell pair, which must be one proton and one neutron. In the mirror ^{13}B, I have argued elsewhere [8] that these admixtures are extremely small, 0.026 and <0.036, respectively. To make the $5/2^+$ state from either of these requires removal of two neutrons from two different major shells. Thus, I estimate that, even if $(s_{1/2})(p_{3/2})$ removal is as strong as $(p_{3/2})^2$ removal, the $5/2^+$ strength should be at most a few percent of ^{11}O(g.s.).

As mentioned by Webb *et al.*, the second $5/2^+$ state involves a $p_{3/2}$ to $s_{1/2}$ excitation of ^{11}O(g.s.). Hence, its population in two-neutron removal from ^{13}O(g.s.) should be even weaker.

These predictions are listed in Table II, where they are compared with relative yields used in the spectrum fit of Webb *et al.*

I was able to reproduce the experimental ^{11}O to ^{9}C + $2p$ decay spectrum using only the g.s. of ^{11}O [9]. The energy and width needed were quite close to those predicted previously [10,11]. Thus, I consider it very unlikely that the ^{11}O decay spectrum contains excited states at anything near the magnitudes used by Webb *et al.* If the ℓ value(s) of the $2p$ decay pair can be determined, then the situation could be clarified.

TABLE I. Estimates of $^{11}\text{B} \times \nu(\text{sd})^2$ neutron intensity in ^{13}B(g.s.).

Intensity	Reference
0.33[a]	2
0.25(3)[b]	3
0.30(3)[c]	3
0.21(2)[d]	3
0.25(5)	4

[a] *R* matrix· using a $^{14}\text{B}(1^+)$ width of 49 keV and no reduction for $S < 1$.
[b] As above, but with $S(^{11}\text{B}\to{}^{12}\text{B}(1^+)) = 0.75(5)$.
[c] Potential model analysis, using width of 49 keV and $S = 0.75(5)$.
[d] As above, but using width of 34(3) keV extracted in Ref. [3] from data of Ref. [2].

TABLE II. Current predictions compared with relative populations of states included in fit to $^{11}\text{O}\to{}^{9}\text{C} + 2p$ spectrum (energies and widths in MeV) [1].

J^π	Predicted contribution[a]	E_r[b]	Γ[b]	Contribution by Webb *et al.* [1]
$3/2^-$	1.0	4.16	1.30	39%
$5/2^+$	0.02–0.04	4.65	1.06	29%
$3/2^-$	0.02(1)	4.85	1.33	
$5/2^+$	<0.02–0.04	6.28	1.96	32%

[a] Present.
[b] Reference [1].

III. SUMMARY

In summary, I have estimated the relative yields expected for the g.s. of ^{11}O and three excited states in $2n$ removal from ^{13}O. Ratios exc./g.s. are predicted to be at most a few percent for each excited state, compared to ratios near unity suggested in a recent treatment of ^{11}O.

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