$2p$ decays of ^{11}O

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In a potential model, I have estimated decay widths for ^{11}O to ^{9}C $+ 2p$ for sequential decay through ^{10}N resonances and by simultaneous $2p$ (^{2}He) decay by integrating over the relevant energy profiles. Results indicate that sequential decays through positive-parity resonances are only slightly smaller than those through negative-parity resonances. Simultaneous decay is predicted to be larger than sequential.

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I. INTRODUCTION

The mirror energy difference between ^{11}Li and ^{11}O depends on the occupancy of the $2s_{1/2}$ orbital because of the so-called Thomas-Ehrman effect. Various estimates of this fractional occupancy $P(s^2)$ have been made. From a detailed analysis of matter radii in core $+2n$ nuclei, Sherr and I estimated $P(s^2) = 0.33(6)$ for ^{11}Li [1]. The history of other determinations is outlined there. With newer data [2], a reanalysis [3] resulted in $P(s^2) = 0.31^{+0.02}_{-0.03}$.

With the earlier value of $P(s^2) = 0.33(6)$, a potential model plus the assumption of mirror symmetry resulted in a prediction of $S_{2p} = -4.46(7)$ MeV for the separation energy of ^{11}O [4]. With the slightly revised $P(s^2)$, this changes to $S_{2p} = -4.488^{+0.024}_{-0.036}$. The estimated uncertainty in the procedure provides an additional uncertainty of about 100 keV. Here I discuss estimates of the decay widths of ^{11}O via $2p$ emission to ^{9}C. Throughout the remainder of the paper, I use $E_{2p} = 4.5$ MeV. For $P(s^2) = 0.33$, I estimated $P(d^2) = 0.09$, leaving $P(p\ \text{shell}) = 0.58$—all of which I have kept constant in what follows.

II. CALCULATIONS AND RESULTS

Decays of ^{11}O to ^{9}C can involve sequential decays through broad resonances in ^{10}N, simultaneous ^{2}He decays to ^{9}C, or so-called democratic ^{9}C$+p+p$ decays. In the present paper, I estimate widths for the first two processes. [I do not know how to compute the third.]

A. Sequential decays

At least four broad resonances in ^{10}N [5] should be available for sequential decays. These are 1^- and 2^- arising from adding a $2s_{1/2}$ proton to ^{9}C; and 1^+ and 2^+ whose dominant structure is a $p_{1/2}$ proton hole in the ground state (g.s.) of ^{11}O. A recent ^{9}C$+p$ elastic-scattering experiment reported two s-wave resonances [6]. Their energies and widths are summarized in Table I. The compilers [5] suggest that the resonance at 2.64 MeV that was observed in the ^{10}B(^{14}N,^{14}B)^{10}N reaction [7] is the mirror of the probable 1^+ state at 0.24 MeV in ^{10}Li. Its mirror energy difference is consistent with this interpretation. A 2^+ resonance of the same structure should exist about 0.3–0.7 MeV higher. For purposes of the present discussion, I assume the 2^+ resonance energy is 3.2 MeV. These are also listed in Table I.

Decays through the negative-parity resonances will involve successive emission of $2s$ protons, whereas decays through positive parity will involve $1p$ protons.

A calculation of the widths for sequential decays through these resonances involves an integral over the energy profile of the intermediate-state resonances. The relevant equation is

$$\Gamma_{\text{seq}}(E_T) = \frac{\int \text{Prof}(E_{9p})\Gamma(E_T - E_{9p})dE_{9p}}{\int \text{Prof}(E_{9p})dE_{9p}},$$

where E_{9p} is the energy of the second proton in the sequential decay, $E_T - E_{9p}$ is the energy of the first one, and Prof is a profile function of Breit-Wigner shape. In the present case, E_T is 4.5 MeV. For evaluation of this expression, the ^{10}N$+p$ widths were calculated in a potential well with geometric parameters $r_0, a = 1.26$, 0.60 and $r_{0c} = 1.40$ fm. For the ^{9}C$+p$ profile functions of the four relevant ^{10}N resonances, I used widths computed in the same potential. These are listed in Table II along with the results. For this evaluation, I assumed the 1^- was below the 2^- in ^{10}N, even though the experiment [6] allows for either order. This ordering has little effect on the total width, but the 2^- intermediate resonance is favored over 1^- by a factor of $5/3$ from the spectroscopic factors. If the branching ratio could be determined in the sequential decay, the ordering could thus be established.

With these estimates, the total width for the sequential decay of ^{11}O should thus be about 1.6 MeV.

B. Simultaneous decays

For simultaneous ^{2}He decay, the calculation involves an integral over the energy profile of the $2p$ pair. I have used the same profile function [8] that Sherr and I utilized earlier

TABLE I. Properties of low-lying resonances in ^{10}N. (Energies and widths in MeV.)

J^π	E_p	Γ	Reference
1^-	1.9(2)	$2.5^{+2.0}_{-1.5}$	[6]
2^-	2.8(2)	$2.0^{+0.7}_{-0.5}$	[6]
1^+	2.64(40)	2.3(16)	[5,7]
2^+	3.2	2.55	Estimated

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TABLE II. Widths (MeV) for sequential $2p$ decays of ^{11}O through the ^{10}N resonances listed.

$E_p(^{10}\mathrm{N})$	$\Gamma(^{10}\mathrm{N})$	J^π	$\Gamma_{sp}(^{11}\mathrm{O})$	S	$\Gamma_{\mathrm{calc}}(^{11}\mathrm{O})$
1.9	1.95	1^-	1.40	0.75×0.33	0.35
2.8	2.5	2^-	1.34	1.25×0.33	0.55
Sum					0.90
2.6	2.3	1^+	0.845	0.75×0.58	0.37
3.2	2.55	2^+	0.495	1.25×0.58	0.36
Sum					0.73

[9,10]. The relevant equation is

$$\Gamma_{\mathrm{sim}}(E_T) = \frac{\int \mathrm{Prof}(E_{\mathrm{int}})\Gamma(E_T - E_{\mathrm{int}})dE_{\mathrm{int}}}{\int \mathrm{Prof}(E_{\mathrm{int}})dE_{\mathrm{int}}}.$$

Here, E_{int} is the internal pp energy in ^{2}He, Prof is the pp profile function, and $\Gamma(E)$ was calculated in a Woods-Saxon well (plus Coulomb) for a di-proton, i.e., a mass-two, charge-two cluster, using $r_0,a = 1.3, 0.60$ fm.

In this decay, if the two decay protons come from the $1p$ shell, the number of nodes in the radial wave function is $n = 1$, whereas if they come from the sd shell, n is 2. For the $L = 0$ $2p$ cluster spectroscopic factors, I use $S = 0.50$ [11] for a pure p-shell $^{11}\mathrm{O} \to {}^9\mathrm{C} + 2p$ ($n = 1$), and I compute $S(n = 2)$ for the pure $(sd)^2$ part from the d^2/s^2 ratio $= 0.22/0.78$ in the $(sd)^2$ wave function. The results of the simultaneous decay calculation are listed in Table III.

The $n = 1$ and 2 widths should be added coherently so that the total width for simultaneous decay would thus be 2.5 MeV, which seems quite large considering the predicted sequential widths given above. It would appear that simultaneous (^{2}He) decay should compete successfully with the sequential width.

III. DEPENDENCE ON $P(s^2)$

As noted, all the numerical results presented so far were obtained from a value of $P(s^2) = 0.33$. For other values of this quantity, the dependences are as depicted in Figs. 1 (seq) and 2 (sim). If these calculations are reliable and if the contributions from sequential and simultaneous decays can be separated, such a measurement would provide an independent determination of $P(s^2)$.

IV. SUMMARY

In conclusion, I have estimated decay widths for ^{11}O to $^9\mathrm{C} + 2p$ for sequential decay through ^{10}N resonances

TABLE III. Calculated widths (MeV) for simultaneous decay $^{11}\mathrm{O} \to {}^9\mathrm{C} + 2p$.

n	Γ_{sp}	S	Γ_{calc}
1	1.55	0.29	0.45
2	2.40	0.34	0.81

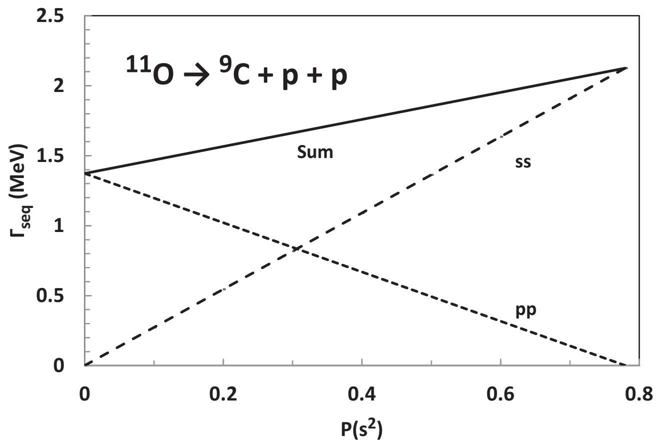

FIG. 1. As a function of $P(s^2)$ in ^{11}O, calculated widths for sequential decays through positive-parity ^{10}N resonances (short dashed line), through negative-parity resonances (long dashed line), and their sum (solid line).

and by simultaneous $2p$ (^{2}He) decay. For the former, I integrated over the energy profiles of the ^{10}N resonances; for the latter, I integrated over a $2p$ profile function employed previously. Results indicate that sequential decays through positive-parity resonances are only slightly smaller than those through negative-parity resonances. Simultaneous decay is predicted to be comparable to or larger than sequential decay.

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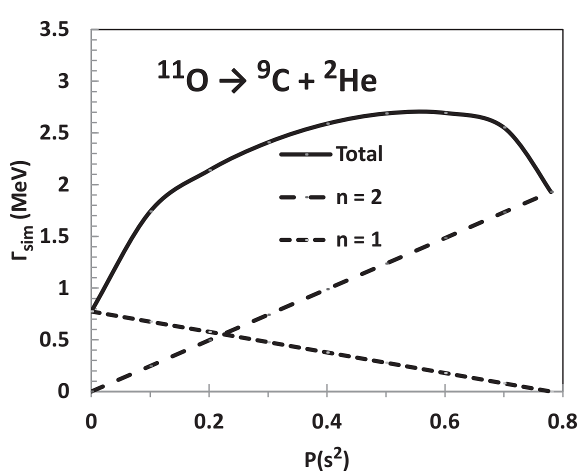

FIG. 2. The same as in Fig. 1, but for simultaneous ^{2}He decay from the p-shell component of ^{11}O(g.s.) (short dashed line), from the $(sd)^2$ component (long dashed line), and from the total (solid line). (The $n = 1$ and $n = 2$ amplitudes have been added coherently.)

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