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Energy and width of ^{11}O(g.s.)

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I have used a potential model and a convolution procedure to compute energy-dependent widths for simultaneous ^{11}O(g.s.)$\rightarrow$^{9}C + $2p$ decay. A Breit-Wigner shape calculated with those widths provides excellent agreement with recent experimental data.

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In an experimental tour de force, Webb *et al.* [1] produced the extremely proton-rich nucleus ^{11}O. They bombarded a ^{9}Be target with secondary beams of $E/A = 69.5$ MeV ^{13}O and detected ^{9}C + $2p$ in coincidence following $2n$ removal. They observed a broad rather structureless peak near 4.7 MeV with a width of about 2.9 MeV. This width is significantly larger than the experimental resolution width, which is reported as 0.45 MeV at $E_{2p} = 4.5$ MeV. They concluded that the peak was too broad to correspond to a single state.

They then performed a Gamow coupled-channel shell-model calculation in which they assumed the ^{9}C core is a deformed rotor, and ^{11}O is obtained by coupling two protons to rotational states of ^{9}C. They obtained several low-lying resonances, including two $3/2^-$ and two $5/2^+$. Resonances having $J^\pi = 1/2^+, 3/2^+$, and perhaps $1/2^-$ should also exist at low excitation. In their analysis, they first attempted a fit with the two $3/2^-$ resonances, but the best-fit spectrum was still too narrow, causing them to include contributions from four resonances—two with $J^\pi = 3/2^-$ and two having $J^\pi = 5/2^+$. They adjusted a single potential parameter to shift the overall spectrum for the best fit, which gave the positions and contributions listed in Table I.

Sherr and I used mirror symmetry and a potential model to compute the mirror energy difference (MED) between ^{11}Li and ^{11}O [2]. The known mass excess of ^{11}Li then led to a prediction of the separation energy of ^{11}O(g.s.) (ground state). This MED is especially sensitive to the s^2 occupancy, $P(s^2)$ because of the so-called Thomas-Ehrman effect. Luckily, the matter radius is also quite sensitive to $P(s^2)$, especially for small separation energies as in ^{11}Li. Several experiments have extracted this matter radius [3–6]. Sherr and I used a weighted average of $R_m = 3.41(8)$ to estimate $P(s^2) = 0.33(6)$ [7], corresponding to $E_{2p}(^{11}\mathrm{O}) = 4.46(9)$ MeV [2]. A new measurement [8] of R_m and of the radius of the neutron distribution led to a minor modification: $P(s^2) = 0.31^{+0.02}_{-0.03}$ and $E_{2p} = 4.49(11)$ MeV [9] where this uncertainty includes an estimated 100-keV uncertainty in the procedure.

Later, I computed expected widths for sequential proton decay through resonances in ^{10}N and for simultaneous $2p$ decay [10]. These predictions are listed in Table II. Note that the predicted width for simultaneous $2p$ decay (if the $n = 1$ and 2 contributions are added coherently) is quite close to the width of the peak observed in Ref. [1]. [The $n = 1$ contribution corresponds to emission of two $1p$-shell protons, and $n = 2$ corresponds to emission of two sd-shell protons.] Sequential decay should involve at least four broad resonances in ^{10}N [11]. 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 g.s. of ^{11}O. A recent ^{9}C + p elastic-scattering experiment reported two s-wave resonances [12]. Reference [11] suggested that a resonance at 2.64 MeV in the ^{10}B(^{14}N, ^{14}B)^{10}N reaction [13] 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 is unknown but should exist about 0.3–0.7 MeV higher.

Reference [1] briefly mentions ^{12}O. I note that the Barker paper [14] cited by Ref. [1] predicted “an upper limit of 5 keV on the width of the ^{12}O ground state due to ^{2}He emission,” compared with the accepted experimental value of 51(19) keV [1] and more recent theoretical values of 31(3) [15] and 18^{+4}_{-3} keV [1]. My calculated ^{11}O widths could be slightly too large. A more complex structure calculation could put more strength in states at higher excitation thereby reducing spectroscopic factors for the lowest states. But, I expect this to be a relatively minor effect.

I have used the simultaneous $2p$ decay procedure to compute expected widths as a function of energy from 0.2 to 10 MeV. I then used these energy-dependent widths to construct a Breit-Wigner curve to compare to the data of

TABLE I. States included in a fit to ^{11}O$\rightarrow$^{9}C + $2p$ spectrum (energies and widths in MeV) [1].

J^π	E_r	Γ	Contribution(%)
$3/2^-$	4.16	1.30	39
$5/2^+$	4.65	1.06	29
$3/2^-$	4.85	1.33	
$5/2^+$	6.28	1.96	32

TABLE II. Predicted properties of ^{11}O (values in MeV).

Quantity	Value[a]
E_{2p}	4.49(11)[b]
Γ_{seq} through 1−, 2−	0.90
Γ_{seq} through 1+, 2+	0.73
Γ_{seq} sum	1.6
Γ_{sim} $n = 1$	0.45
Γ_{sim} $n = 2$	0.81
Γ_{sim} coherent sum	2.46[c]

[a] Reference [10] unless otherwise noted.

[b] References [2,9].

[c] With the calculated energy dependence, this width becomes 2.53 MeV at $E = 4.75$ MeV.

Ref. [1]. Because of the energy dependence of the widths, this calculated peak is somewhat asymmetric. Figure 1 displays the data of Ref. [1] with their background function subtracted. No correction has been made for experimental resolution, but the resolution width is quite small—quoted to be 0.45 MeV at $E_{2p} = 4.5$ MeV. I made a slight adjustment to the predicted energy of the resonance. The width is easily adjusted by multiplying the computed widths by a constant at all energies. The dashed curve has $E_0 = 4.70$ MeV and $\Gamma(E_0) = 2.17$ MeV; the solid curve corresponds to $E_0 = 4.75$ and $\Gamma(E_0) = 2.51$ MeV. The agreement between the experimental points and the calculated solid curve seems to be at least as good as the fit in Ref. [1]. Both exhibit an excess of counts near 2 MeV. The reason for this is not understood. The cause could be an imperfect subtraction of a ^{12,13}O background or a slightly incorrect $2p$ background function. Correcting for the experimental resolution will not fix the problem. Evidence of a slight excess of counts near 7 MeV may indicate the presence of other weak states.

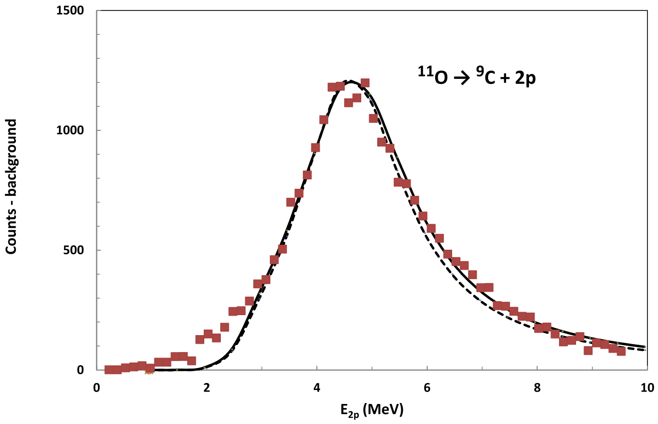

FIG. 1. Data points are the points from Fig. 1(b) of Ref. [1] with their background subtracted. Curves are Breit-Wigner shapes with energy-dependent widths: $E_0 = 4.7$, $\Gamma(E_0) = 2.17$ MeV (dashed line), and $E_0 = 4.75$ MeV, $\Gamma(E_0) = 2.51$ MeV (solid line).

To summarize, the $2p$ breakup data for $^{11}\text{O} \to {}^{9}\text{C} + 2p$ are reasonably well reproduced by a calculation that includes only the ^{11}O(g.s.). The extracted resonance energy of 4.75 MeV is near the earlier prediction of 4.49(11) MeV. The width needed is remarkably close to the value previously predicted for simultaneous $2p$ decay.

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