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Configuration of ^{18}O(7.12 MeV, 4^+)

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Alpha-particle widths calculated in a potential model demonstrate that the 7.12-MeV, 4_2^+ state of ^{18}O has about the right alpha width for the dominant four-particle–two-hole 4^+ state.

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In ^{18}O, it has been known for a long time [1,2] that all the positive-parity states [3] below 8 MeV excitation can be understood as those arising from an $(sd)^2$ shell-model space plus one collective state of each $J^\pi = 0^+, 2^+$, and 4^+. The dominant configuration of these collective states is four-particle–two-hole ($4p$-$2h$), even though there is some evidence [2] that they may be even more collective than that configuration would suggest. The $4p$-$2h$ states have been identified as the 0_2^+, 2_3^+, and 4_2^+ states at 3.63, 5.25, and 7.12 MeV, respectively. Of course, mixing occurs between $2p$ and $4p$-$2h$ states, but that mixing can be understood [2].

Recent $B(E2)$ measurements [4,5] cast doubt on the dominant $4p$-$2h$ assignment for the 4^+ at 7.12 MeV. A new measurement and the implications are discussed in an even more recent paper [6]. It now appears that $B(E2)$ for $4_2^+ \rightarrow 2_3^+$ is only about a third of the value expected for a pure $4p$-$2h$ transition. We explore this fact in light of other available information.

A $(0+2)\hbar\omega$ calculation of ^{18}O contains only three low-lying 4^+ states: $(d\frac{5}{2})^2$, $(d\frac{5}{2})(d\frac{3}{2})$, and $4p$-$2h$. The absence of a large S_n in ^{17}O(d,p) limits the $2p$ amplitude for the 7.12-MeV state. The dominantly $(d\frac{5}{2})(d\frac{3}{2})$ 4^+ state has been suggested [7] to lie near 9 MeV. The lowest-lying $4p$-$2h$ states should have large parentage for ^{14}C+α. The α-particle amplitudes for the lowest three 0^+, three 2^+, and two 4^+ states are in the literature [8], reproduced here as Table I. We note that the expected $(sd)^4$ α amplitude is about the same for 0_2^+, 2_3^+, and 4_2^+.

Experimentally, [5,9] the quantity $\frac{\Gamma_\alpha \Gamma_\gamma}{\Gamma}$ for the 7.12-MeV state is 51 ± 7 meV. The newest value [6] of $\frac{\Gamma_\gamma}{\Gamma}$ is 0.561 ± 0.013. The ratio of the two gives $\Gamma_\alpha = 91 \pm 13$ meV. We compare this value below with that expected for the $4p$-$2h$ 4^+ state.

In ^{20}Ne, the 0^+, 2^+, and 4^+ members of the g.s. band are bound, but the 6^+ is unbound, with $\Gamma_\alpha = 0.11 \pm 0.02$ keV [3]. The single-particle α width calculated in a Woods-Saxon well of radius $R = 3.53[= 1.40(16)^{\frac{1}{3}}]$ and diffusivity $a = 0.60$ is 0.511 keV. (This calculation assumes $2N + L = 8$, where N is the number of nodes in the radial wave function.) Combining the experimental Γ_α for ^{20}Ne(6^+) with our calculated $\Gamma_{\text{s.p.}}$ gives $S_\alpha = 0.215 \pm 0.039$. The theoretical α-particle amplitude [10] for this state is $(\frac{20}{16})^4(\frac{3}{128})\sqrt{70}$, giving an expected S_α of 0.229 — in quite good agreement. Of course, the value of $\Gamma_{\text{s.p.}}$ depends sensitively on the chosen value of R, but we intend to use a consistent radius for ^{18}O and ^{20}Ne.

If we scale the ^{14}C+α and ^{16}O+α radii as $A_0^{\frac{1}{3}}$, then $\Gamma_{\text{s.p.}}$ for a 4^+ $(sd)^4$ state ($N = 2$) at 7.117 MeV is calculated to be 266 meV. If we use the same radius in ^{18}O as in ^{20}Ne (instead of the same radius parameter, $r_{0\alpha}$) we get $\Gamma_{\text{s.p.}} = 335$ meV. We thus adopt $\Gamma_{\text{s.p.}} = 300 \pm 34$ meV, leading to $S_\alpha(7.12) = 0.30 \pm 0.05$ — in good agreement with the maximum of 0.287 expected for a pure ^{14}C$\otimes\alpha$ state. [The value is larger in ^{18}O than in ^{20}Ne because of the $(\frac{A+4}{A})^4$ factor [10] in the amplitude.] Actually, combining the α amplitudes from Table I with $\Gamma_{\text{s.p.}}$ for the two pure configurations gives $\Gamma_\alpha(\text{mixed}) = 84 \pm 9$ meV as the width expected for the 4_2^+ state of [2], in comparison with the experimental value of 91 ± 13 meV. We thus see that ^{18}O(7.12) has at least as much α strength as expected (Table II) for a dominantly $4p$-$2h$ state. We thus consider the $4p$-$2h$ character of this state confirmed.

What, then, are we to make of the $B(E2)$'s? Our only conclusion is that the mixing must be somewhat different from that in LSF or in the $(0+2)\hbar\omega$ shell-model calculations [6]. Of course, small amplitudes in wave functions can, through destructive interference, cause significant reduction in $B(E2)$ strengths. Such a situation is less likely for α strengths because basic states not already included have little or no ^{14}C+α strength. In addition, the two largest α amplitudes for the 7.12-MeV state are in phase (opposite signs in Table I are constructive).

A similar situation is now well known in a nearby nu-

TABLE I. Alpha-particle spectroscopic amplitudes (from [8], using wave functions of [2]) for ^{14}C+$\alpha \rightarrow ^{18}$O.

J^π	E_x (MeV)	A_6[a]	A_8[a]
0_1^+	0.0	0.2011	-0.1592
0_2^+	3.63	-0.0030	0.4405
0_3^+	5.33	-0.1275	-0.2604
2_1^+	1.98	-0.1723	0.1859
2_2^+	3.92	0.0590	-0.2685
2_3^+	5.25	-0.1087	-0.4249
4_1^+	3.55	0.1092	-0.0348
4_2^+	7.11	-0.0563	0.4887

[a] Subscripts on A are 6 for the two-particle component of the ^{18}O wave function and 8 for the $4p$-$2h$ component.

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cleus, ^{19}F, for the $\frac{11}{2}^-$ states. There, the dominantly ^{15}N$\otimes\alpha$ $\frac{11}{2}^-$ state has too little $E2$ strength [11], but the proper amount of α spectroscopic strength [12–14].

The combined $(sd)^2$ and $4p$-$2h$ $4^+\rightarrow2^+$ $B(E2)$ strength is conserved with any mixing. A smaller value for 7.12→5.26 implies a larger value somewhere else. The most likely location for the missing strength is in $2_3^+\rightarrow4_1^+$ and/or $4_3^+\rightarrow2_3^+$. The former $B(E2)$ is poorly known, the latter totally unknown. In fact, a measurement of both Γ_α and Γ_γ for the third 4^+ state (suggested at ~9 MeV) would be welcome. This state is also unbound to n decay, so that the total width is probably mostly neutron width, but perhaps some combination of experiments such as ^{14}C(α,γ), ^{17}O(n,γ), and ^{17}O(n,α) can clarify the situation.

TABLE II. Alpha widths (meV) for ^{18}O(7.12 MeV).

Source	Γ_α
Experimental	91 ± 13
Theory:	
Pure $4p$-$2h$	86 ± 9
Mixed $2p$ and $4p$-$2h$[a]	84 ± 9

[a] From [2,8] as in Table I.

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