PHYSICAL REVIEW C, VOLUME 61, 024313

Properties of ^{19}Ne (7.07 MeV) and its mirror in ^{19}F

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(Received 29 July 1999; published 19 January 2000)

The astrophysically important $l=0$ resonance that occurs at an excitation energy of 7.07 MeV in ^{19}Ne has an appreciable fraction of the $2s\frac{1}{2}$ single-proton strength. Hence, the excitation energy in ^{19}Ne should be considerably lower than for its mirror in ^{19}F, which we predict at $E_x=7.4\pm0.1$ MeV.

PACS number(s): 21.10.Sf, 21.10.Hw, 25.40.Ny, 27.20.+n

In ^{19}Ne, a level at an excitation energy of $E_x=7.07$ MeV has attracted lots of attention because of its importance for astrophysics. Observed first in ^{20}Ne(^{3}He, α) [1], it has since been observed by several groups, in at least two other reactions. In ^{19}F(^{3}He,t), at 30 MeV bombarding energy, it is observed [2] as a final state with noticeable width. The authors quote a total observed width of 46 keV, with an experimental resolution width of 24 keV. These results imply a natural width of the state between 22 and 33 keV—depending on the shape of the experimental resolution function. (If any shape is convoluted with a natural Lorentzian line shape, the widths do not add in quadrature.) The authors quote $\Gamma_{tot}=39\pm10$ keV. The state can decay by proton and/or α emission (and gammas, of course). The γ width is negligible compared to the other two, and we expect $\Gamma_p+\Gamma_\alpha=\Gamma_{tot}$.

The authors of Ref. [2] detected p's and α's in coincidence with the outgoing triton, the decay-particle detector covering a range of 90°–145° in the laboratory. They fit the decay angular dependence with a sum of Legendre polynomials, in order to extract Γ_p/Γ_α—even though in a suitable coordinate system the l value for each decay should be unique. We return to the l values later. The p/α branching ratio is quoted as $\Gamma_p/\Gamma_\alpha=0.58$, with a somewhat large uncertainty.

The state has also been observed [3,5] as a resonance in $p(^{18}\mathrm{F},^{15}\mathrm{O})\alpha$. Various groups agree roughly on the resonance energy—$E_{p\,c.m.}=638$–659 keV, but differ on the widths, as listed in Table I. There is also a disagreement of about a factor of 2 (larger in Ref. [5]) in the absolute (p,α) strength. For any of the proton widths that have been quoted, the resonance must have $l_p=0$. The proton width is significantly larger than the single-particle (s.p.) proton width for $l_p>0$. Hence, J^π is $\frac{3}{2}^+$ or $\frac{1}{2}^+$ [since ^{18}F(g.s.) is 1^+]. Either of these corresponds to $L_\alpha=1$, for which any of the measured alpha widths are about 10^{-2} of an alpha-single-particle width. For any of these widths, this resonance dominates the ^{18}F(p,α) reaction at temperatures of astrophysical interest, and it may make a significant contribution to ^{18}F(p,γ). The latter point is uncertain because γ widths are not known. If the mirror in ^{19}F could be identified, γ information in ^{19}F would reduce the uncertainties in the (p,γ) computation. Despite some attempts [4,6] to link ^{19}Ne (7.07) to ^{19}F (7.10), our calculations show that the ^{19}F mirror lies much higher.

We have used a potential model—Woods-Saxon nuclear well with radius and diffusivity parameters of $r_0=1.25$, $a=0.65$ fm, plus Coulomb potential of a uniformly charged sphere. The resulting s.p. width for $^{18}\mathrm{F}+2s\frac{1}{2}$ proton is $\Gamma_{s.p.}=28$ keV. Thus, whether the state is $\frac{3}{2}^+$ or $\frac{1}{2}^+$, $S_p=\Gamma_p/\Gamma_{s.p.}$ is large—using Γ_p from Ref. [4], $S_p=0.18\pm0.06$, whereas Γ_p from Ref. [2] results in $S_p=0.50\pm0.14$. We favor the larger value of S because of systematics, as we discuss later.

With the potential that puts the $^{18}\mathrm{F}+p$ resonance at $E_{p\,c.m.}=0.655$ MeV, we have calculated the energy of the bound state $^{18}\mathrm{F}+n$ to be $E_n=-2.51$ MeV, corresponding to $E_x=7.92$ MeV in ^{19}F. Of course, this is for a state with unit spectroscopic factor. Because $S<1$, the excitation energy difference will be less, but for any reasonable S, E_x in ^{19}F is considerably larger than in ^{19}Ne. For example, if $S=0.50$, then $E_x(^{19}\mathrm{F})=7.50$ MeV, while $S=0.18$ corresponds to $E_x(^{19}\mathrm{F})=7.23$ MeV. This computation assumes that the non-s.p. part of the wave function has a negligible ΔE_x. This may or may not be true. Other $(sd)^3$ states should have comparable E_x in ^{19}Ne and ^{19}F, as it is only the $s\frac{1}{2}$ single-particle component that produces a large shift. An $(sd)^3$ shell-model calculation for ^{19}F puts two $\frac{3}{2}^+$ states near

TABLE I. Energies and widths (keV) of the 7.07 MeV level in ^{19}Ne.

E_x (MeV)	E_p (keV)	Γ_p	Γ_α	Γ_{tot}	Reaction	Ref.
7.049	638 ± 15	13	24	37 ± 5	$p(^{18}\mathrm{F},\alpha)$	[5]
7.063	652 ± 4	5.0 ± 1.6 [a]	8.6 ± 2.5 [a]	13.6 ± 4.6	$p(^{18}\mathrm{F},^{15}\mathrm{O})$	[4]
7.070	659 ± 7	14 ± 4	25 ± 6	39 ± 10 [b]	$^{19}\mathrm{F}(^3\mathrm{He},t)$	[2]

[a] Analysis assumed $\Gamma_p/\Gamma_\alpha=0.58$ from Ref. [2].

[b] Measured width 46 keV, resolution width 24 keV.

TABLE II. ^{19}Ne (7.07) and its mirror in ^{19}F (all energies in keV).

^{19}Ne					^{19}F (computed)	
E_x	E_p	Γ_p	$\Gamma_{s.p.}$	S	E_n	E_x
7066[a]	655[a]	11 ± 3[a]	28[b]	0.40 ± 0.12[b]	-3020	7410 ± 100

[a] Our ''average'' of the values in Table I.
[b] Our calculation.

here—at 6.63 and 7.73 MeV—whereas three are already known [7]—at 6.497, 6.528, and 7.262 MeV—in addition to the missing mirror of ^{19}Ne (7.07). Two lower $\frac{3}{2}^+$ states at 3.908 and 5.502 MeV, are known to be core excited in nature [8,9].

What other $\frac{3}{2}^+$ states might exist near here? (We assume $J^\pi=\frac{3}{2}^+$, even though we know of no evidence that favors $\frac{3}{2}^+$ over $\frac{1}{2}^+$.) The same calculation that puts an eight-particle four-hole ($8p-4h$) 0^+ state at $E_x=7.19$ MeV in ^{20}Ne puts a $7p$-$4h$ $\frac{3}{2}^+$ state at $E_x=5.37$ MeV in ^{19}Ne. This state will be higher in ^{19}Ne than in ^{19}F by an amount 0.22–0.24 MeV. (Generally, hole states have higher E_x in the larger Z member of an isospin multiplet.) If this state mixed appreciably with the $2s\frac{1}{2}$ single-particle state, the mixture might conspire to have a small E_x shift, as the shifts are opposite for the two components. But then there would be another $\frac{3}{2}^+$ state with significant s.p. strength, and none is known. (For that matter, where is the $\frac{1}{2}^+$ s.p. state that should be slightly above the $\frac{3}{2}^+$?) Such mixing is further unlikely, because there is no direct mixing between $7p$-$4h$ and $3p$ states.

Considering the uncertainties above, we expect the ^{19}Ne (7.07) mirror will be located (see Table II) at 7.41 ±0.10 MeV in ^{19}F. This corresponds to $S=0.40$. It is virtually impossible for ^{19}F (7.10) to be the mirror. A known $\frac{3}{2}^+$ at $E_x=7.262$ MeV is a possiblility, but it has a small total width, and Γ_α should be approximately the same in the two nuclei for low L states as unbound as these. There is no direct evidence that ^{19}F (7.10) is the mirror of ^{19}Ne (7.07). A state at 7.114 MeV has a $\frac{7}{2}^+$ assignment in the compilation [7]. There was early mention of the possibility of a $\frac{3}{2}^+$, $\frac{7}{2}^+$ doublet in ^{15}N(α,α). Of 15 states observed [10] in that reaction in this region of excitation, 6 now have J^π assignments [7] that are different from the ones made in (α,α), although five of the six have current J^π assignments that are consistent with the L values of Ref. [10]. Butt *et al.* [6] used ^{15}N(α,γ) to search for the mirror of ^{19}Ne (7.07). Unfortunately, perhaps, they covered only the E_x range 6.066–7.116 MeV. They found a resonance at $E_x=7.101\pm0.001$ MeV, with $\Gamma_\alpha=28\pm1$ keV and gamma decays to states with $J^\pi=\frac{3}{2}^-$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{7}{2}^+$. Even though they refer to the ''well-established $\frac{7}{2}^+$ state at $E_x=7.114$ MeV ($\Gamma=32$ keV),'' it is not clear whether they think there is one state here or two. If their 7.10-MeV level is indeed a single state, its γ decays (especially to the $\frac{3}{2}^-$) favor an assignment of $\frac{3}{2}^+$. However, if two states are present, the gamma decays can be understood even if neither is $\frac{3}{2}^+$—even if all the γ's are dipole. (For example, a combination of $\frac{1}{2}$ and either $\frac{5}{2}$ or $\frac{7}{2}$ would work.) Of course, the ''well-established $\frac{7}{2}^+$'' and the 7.10-MeV level of Ref. [6] are only 13 keV apart, with widths near 30 keV. And as we point out above, even if a $\frac{3}{2}^+$ level is proven to exist at 7.10 MeV in ^{19}F, it is extremely unlikely to be the mirror of ^{19}Ne (7.07).

In at least two cases, viz. ^{11}N(g.s.) [11,12] and ^{18}Ne(3^+) [13,14], our potential model appears to fail by more than 100 keV for an *s*-wave resonance. But in both instances, the proton level is found lower than calculated. In the present situation, a similar discrepancy would make the neutron level, i.e., ^{19}F, even higher.

We suggest that someone do the ^{18}F (d,p) reaction. The state sought should be a very strong $l=0$, located near 7.4 ±0.1 MeV. That reaction might also find the $\frac{1}{2}^+$ member, which should lie slightly higher. In ^{19}F (d,p) [15], two $l=0$ transitions dominate -1^+ and 0^+ states at $E_x=3.49$ and 3.53 MeV, with $S=0.40$ and 0.28, respectively. The centroid of these latter two states is at $E_n=-3.10$ MeV, very close to our prediction for the ^{19}F states. And, their spectroscopic factors are very close also, if we use the larger of the published proton widths. Even if the proton width is the smaller of the two, the state should still be strong in ^{18}F(d,p). And with the lower Γ_p, there is probably another $\frac{3}{2}^+$ state with the missing $l=0$ strength. Just finding the number and location of $l=0$ states in this region of ^{19}F would be extremely valuable.

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