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Resolution of a Dilemma in ^{20}Ne†

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Spectroscopic strengths of 0^+ states observed in the reaction ^{19}F(^{3}He,d)^{20}Ne, together with calculations of α-particle widths, imply that the large α width of the 6.72-MeV state arises from mixing with a state of fp-shell character. A long-standing dilemma is thus resolved.

There are three excited 0^+ states in ^{20}Ne at E_x = 6.72, 7.20, and ~8.3 MeV.[1] From previous analyses of one- and two-nucleon transfer data,[2,3] it appears that the dominant configuration of the 6.72-MeV state consists of four nucleons in the $2s$-$1d$ shell outside an ^{16}O core. The 7.20-MeV state has been suggested[4] as an 8p-4h (eight-particle, four-hole) state, the dominant configuration being eight sd-shell nucleons outside a ^{12}C core. These two configurations are consistent with shell-model calculations.[5-7] The 8.3-MeV state has a very large α-particle reduced width,[1] much too large for this state to be of $(sd)^4$ configuration. Yet, the large α width requires good overlap with four nucleons outside an ^{16}O core. Thus, it is likely that the dominant configuration of this state is $(sd)^2(fp)^2$ or $(fp)^4$. The α-particle reduced widths for all three 0^+ states are displayed in Table I. The experimental α widths are from a recent compilation.[1] The single-particle α widths, Γ_α(s.p.), were calculated assuming that the α particle moves in a real Woods-Saxon potential well relative to an ^{16}O core. The well depth was adjusted to obtain the experimental separation energy.

The small α reduced width for the 7.20-MeV state is consistent with its supposed parentage, since its allowed α decay (to the 4p-4h state at 6.06 MeV in ^{16}O) is energetically forbidden. How-

TABLE I. α-particle widths for three excited 0^+ states in ^{20}Ne.

E_x (MeV ± keV)	Γ_α(expt)[a] (keV)	Γ_α(s.p.)[b] (keV)	Γ_α(expt)/Γ_α(s.p.)
6.722 ± 3[a]	15 ± 7	44	0.34 ± 0.16
7.196 ± 4[a]	4	234	0.017
~8.3[c]	~800[c]	1875	~0.43

[a]Ref. 1.
[b]Calculated in a Woods-Saxon well of radius R = 3.52 F, and diffuseness a = 0.60 F. The well depth was adjusted to reproduce the experimental separation energies.
[c]From present work.

ever, the large α reduced width for the 6.72-MeV state has consistently[8] presented a difficulty. Shell-model calculations[5] that correctly account for the single- and two-nucleon configuration of this state predict[8] a very small α reduced width. In fact, any excited $(sd)^4$ 0^+ state will have very little α strength since essentially all the $(sd)^4$ α strength resides in the ground state. This expectation is present both in full shell-model calculations and in SU(3) calculations.[8] However, the experimental evidence contradicts this expectation—the α reduced width listed in Table I for the 6.72-MeV state is actually larger than the value for the ground state (obtained[9] from an analysis of α-transfer data). It is impossible[8] to account for the α strength of the 6.72-MeV state with an $(sd)^4$ or $(sd)^8(1p)^{-4}$ shell-model calculation. However, the results[2] of the reaction $^{19}F(^3He,d)^{20}Ne$ to this state, when compared with shell-model calculations,[5] strongly indicated that the major component of the 6.72-MeV state is indeed $(sd)^4$. The present study appears to remove this difficulty.

We have reinvestigated the reaction $^{19}F(^3He,d)^{20}Ne$, with particular emphasis on extreme forward angles, where states populated by $l_p=0$ are strongest. The experiment was performed in the University of Pennsylvania multiangle spectrograph using 18-MeV $^3He^{++}$ ions. The target consisted of a 35-μg/cm^2 layer of $^{40}CaF_2$ evaporated onto a thin gold backing. A specially designed Faraday cup allowed accumulation of data as far forward as 1.5°.

Spectra were recorded at 1.5° and in 3.75° intervals from 3.75°. A spectrum obtained at 3.75° is shown in Fig. 1. It can be seen that the 7.20-MeV 0^+ state is almost completely absent. The 6.72-MeV 0^+ state is quite strong, as was previously observed.[2] The surprising aspect of this spectrum is the strength of the broad 0^+ state near 8.3 MeV. The angular distribution of this state at forward angles is consistent with it being populated via direct proton stripping with $l_p=0$. This result is inconsistent with the supposed $(sd)^2(fp)^2$ or $(fp)^4$ configuration for this state, unless considerable mixing is present.

The extremely weak $(^3He,d)$ cross section observed for the 7.20-MeV state is strong evidence that it contains little of the $(sd)^4$ configuration. On the other hand, the extremely small α reduced width for the 7.20-MeV state indicates that it has not mixed with the fp shell state. We shall see, however, that all the results are consistent with mixing between the 6.72- and 8.3-MeV states.

We shall then consider the mixing of two states.

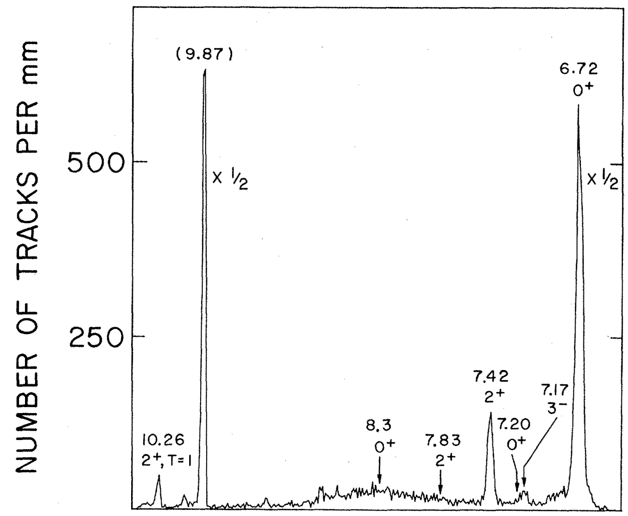

FIG. 1. Deuteron spectrum from the reaction $^{19}F(^3He,d)^{20}Ne$, obtained at $E(^3He)=18$ MeV and $\theta_{lab}=3\frac{3}{4}°$. The 7.20-MeV 0^+ state is extremely weak, whereas the broad 0^+ state near 8.3 MeV is clearly present.

Let Φ_2 be the unperturbed $(sd)^4$ state which is predicted to be near 7 MeV,[5] to have a large $(^3He,d)$ spectroscopic factor,[5] and to have a very small α reduced width.[8] Let Φ_3 be the $(fp)^4$ or $(fp)^2(sd)^2$ state which has a large α reduced width[8] and no $(^3He,d)$ strength and is predicted[8,10] to be near 8 MeV in excitation. The small energy difference between these two states makes it likely that they should mix and thus, after mixing, we have for the wave functions of the physical states $\psi(6.72)$ and $\psi(8.3)$

$$\psi(6.72)=\alpha\Phi_2+\beta\Phi_3,$$

$$\psi(8.3)=-\beta\Phi_2+\alpha\Phi_3,$$

and

$$\alpha^2+\beta^2=1,$$

where we have ignored mixing of both states with the 7.20-MeV state—as required by the data.

Since the state Φ_3 has no proton strength, the observed ratio of proton spectroscopic factors for the two states is just the ratio of α^2 to β^2,

$$S_p(6.72)/S_p(8.3)=\alpha^2/\beta^2.$$

The value of this ratio extracted from the present $^{19}F(^3He,d)^{20}Ne$ experiment is $S_p(6.72)/S_p(8.3)=4.0\pm0.2$, giving $\alpha^2=0.80$ and $\beta^2=0.20$. If we now knew the intrinsic α reduced widths of the states Φ_2 and Φ_3, we could, using these values of α^2 and β^2, calculate the α reduced widths for the 6.72- and 8.3-MeV states.

For Φ_2 we take the α reduced width obtained[8] from shell-model calculations[5] ($\Theta_2^2 = 0.03$). We know that in the present model the summed reduced widths must be conserved. Since the experimental reduced widths total $0.76 = 0.34 + 0.43$, we take $\Theta_3^2 = 0.77 - \Theta_2^2 = 0.74$. Then

$$\Theta_\alpha^2(6.72) = |\alpha\Theta_2 + \beta\Theta_3|^2$$

and

$$\Theta_\alpha^2(8.3) = |-\beta\Theta_2 + \alpha\Theta_2|^2.$$

Using the previously determined values of α^2 and β^2 and taking the signs so as to increase the width of the 6.72-MeV state, we obtain

$$\Theta_\alpha^2(6.72) = 0.29$$

and

$$\Theta_\alpha^2(8.3) = 0.47,$$

which are in remarkable agreement with the experimental values. Thus, the large α reduced width of the 6.72-MeV state appears to have a simple explanation.

In conclusion, we observe mixing between two states whose major configurations appear to be four nucleons outside an ^{16}O core. Furthermore, neither of these states mix strongly with a nearby state of the same J^π whose major configuration is apparently eight sd-shell nucleons outside a ^{12}C core. This result appears logical, in that the presence of different cores should greatly inhibit mixing, whereas states with the same core can mix more easily. Conversely, the degree of mixing among the three 0^+ states, together with the observed α widths and the observed proton spectroscopic factors, lends strong support to the supposed configurations of these three states.

The present explanation is the only one currently available that is in agreement with all the experimental information. Other solutions to the problem may exist. We would be happy (though surprised) if an alternate explanation can be found for the proton and α reduced widths of these excited 0^+ states.

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Shifts of Electron Beam Position Due to Total Reflection at a Barrier

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Just as light beams can undergo position shifts when totally internally reflected, it is found that analogous shifts of an electron beam can occur upon total reflection at a potential barrier. A given shift corresponds to a spin polarization normal to the shift, and thus an initially unpolarized beam will be separated into two polarized beams. These shifts are comparable to the electron Compton wavelength times the number of multiple reflections.

When an electromagnetic wave packet undergoes total internal reflection near the critical angle, various Fourier components in the packet are changed in phase by different amounts depending strongly on the wave vector.[1] These phase changes can result in shifts of position of the wave-packet's centroid in the plane of incidence (longitudinal or Goos-Hänchen shift),[2] or normal to the plane of incidence (transverse shift).[1,3,4] Such shifts are intimately related to the state of polarization of the incident