which is in good agreement with recent theoretical results from Auerbach *et al.*,[13] and the spreading width $\Gamma^+ = \Gamma - \Gamma_p$ is in both cases nearly the same, whereas the partial widths differ by a factor of 2. The derived quantities Δ have very small values near 10 keV, whereas the symmetric term of the enhancement, indicated by $B \approx 40$ keV, cannot be neglected.

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^{12}C(^{13}C, α) Transitions to Possible Eight-Particle, Three-Hole States in ^{21}Ne†

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Excitation functions and energy-averaged angular distributions have been measured for the ^{12}C(^{13}C, α) transitions to the 3.66- and 3.89-MeV states in ^{21}Ne. The similarities observed between these transitions and the ^{12}C(^{12}C, α) transition to the 7.83-MeV 2^+ eight-particle, four-hole state in ^{20}Ne suggest a possible eight-particle, three-hole configuration for the 3.66- and 3.89-MeV states of ^{21}Ne.

In an earlier study[1] of the ^{12}C(^{13}C, α) reaction, performed at a center-of-mass energy of 14.4 MeV, the two states at $E_x = 3.66$ and 3.89 MeV in ^{21}Ne were observed to be selectively populated. The angular distributions were highly asymmetric —that of the 3.89-MeV state was strongly forward peaked and that of the 3.66-MeV state strongly backward peaked. The shapes of the angular distributions were highly suggestive of a direct reaction mechanism, and the present investigation was undertaken to explore this possibility.

Asymmetric angular distributions are not necessarily inconsistent with a compound-nucleus reaction mechanism, particularly if measured at a single incident energy. However, the statistical model of the compound nucleus predicts symmetry about 90° for an angular distribution obtained by averaging over an energy interval corresponding to several states in the compound system. Averaged angular distributions have been obtained using the University of Pennsylvania multiangle spectrograph and tandem accelerator. For these data, the incident energy (center of mass) was varied between 14.28 and 14.52 MeV in eleven equal steps. Good energy resolution was retained by readjusting the magnetic field of the spectrograph at each incident energy to compensate for the variation in the energy of the emitted α particles. The energy loss in the targets was about 80 keV (lab), which is comparable to the step size in which the incident energy was varied.

The resulting angular distributions for the 3.66- and 3.89-MeV states are displayed in Fig. 1. The forward-angle data (circles) were measured using a ^{12}C target and a ^{13}C beam. The back-angle data (crosses) were obtained by interchanging target and projectile and observing this reaction, at forward angles, over the same range of center-of-mass energies. To avoid confusion, the

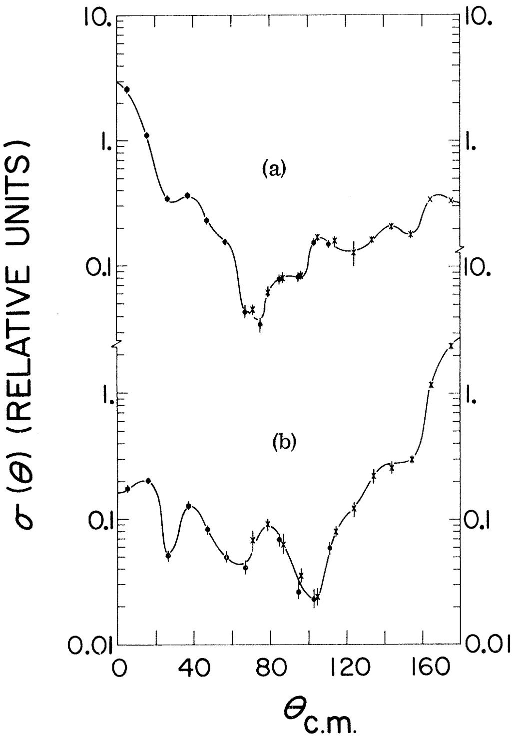

FIG. 1. Energy-averaged angular distributions of the $^{12}C(^{13}C,\alpha)$ transitions to the (a) 3.89- and (b) 3.66-MeV levels of ^{21}Ne obtained while varying the incident (center-of-mass) energy between 14.28 and 14.52 MeV. The forward-angle data (circles) were measured using a ^{12}C target and a ^{13}C beam; the back-angle data (crosses) were obtained by interchanging the target and projectile and observing this reaction at forward angles over the same range of center-of-mass energies.

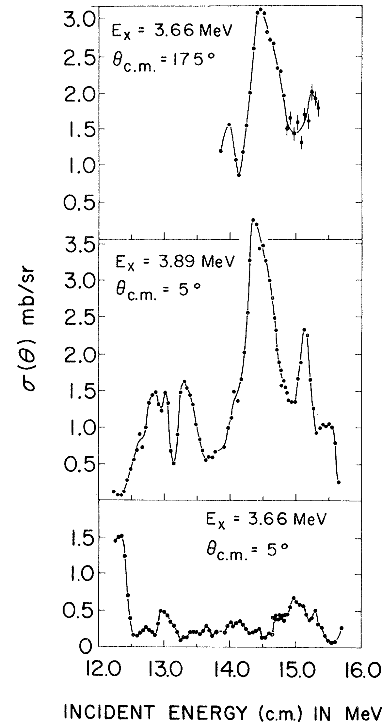

FIG. 2. Forward- and backward-angle excitation functions of the 3.66-MeV level and a forward-angle excitation function of the 3.89-MeV level in the $^{12}C(^{13}C,\alpha)$ reaction. The backward-angle data were obtained by interchanging the target and projectile and observing the products from the $^{13}C(^{12}C,\alpha)$ reaction at forward angles.

data have all been converted to the same coordinate system—that of the $^{12}C(^{13}C, \alpha)$ reaction.

It is evident from Fig. 1 that the high degree of asymmetry in the two angular distributions persists over the 240-keV variation in the center-of-mass energy. If fluctuation widths are less than 240 keV, these results appear to be evidence for some mechanism other than a simple compound process. To determine whether the asymmetries persist over an even larger range of energies, forward- and back-angle yield curves have been measured using a position-sensitive detector in the $3\frac{3}{4}°$ gap of the multiangle spectrograph. [The data at θ(c.m.) = 175° for the 3.66-MeV level were obtained by observing the $^{13}C(^{12}C, \alpha)$ reaction at θ(c.m.) = 5°.]

The excitation functions (shown in Fig. 2) exhibit several unusual and interesting features:
(i) The forward-backward asymmetry of the 3.66-MeV state persists over the entire energy range (13.8 to 15.4 MeV) for which back-angle data were obtained. This asymmetry ranges from a minimum value of about 3 to a maximum of 15. (ii) The forward-angle yield curve of the 3.89-MeV state is remarkably similar to the back-angle yield curve of the 3.66-MeV state. (iii) Both these yield curves exhibit strong "resonances" with large widths (~500 keV).

Features remarkably similar to those enumerated above have recently been observed[2] in the $^{12}C(^{12}C, \alpha)$ transition to the 2^+ state at 7.83 MeV in ^{20}Ne. The similarity also extends to the angular distributions if the effects of the identical target and projectile in the $^{12}C(^{12}C, \alpha)$ reaction are taken into account. For example, as seen in Fig. 3, the sum of the $^{12}C(^{13}C, \alpha)$ angular distributions for the 3.66- and 3.89-MeV levels is very similar in shape to that of the $^{12}C(^{12}C, \alpha)$ transition to the 7.83-MeV state of ^{20}Ne. [The $^{12}C(^{12}C, \alpha)$ angular distribution was obtained at an incident center-of-mass energy of 13.5 MeV, corresponding to the strongest peak observed in the forward-angle ex-

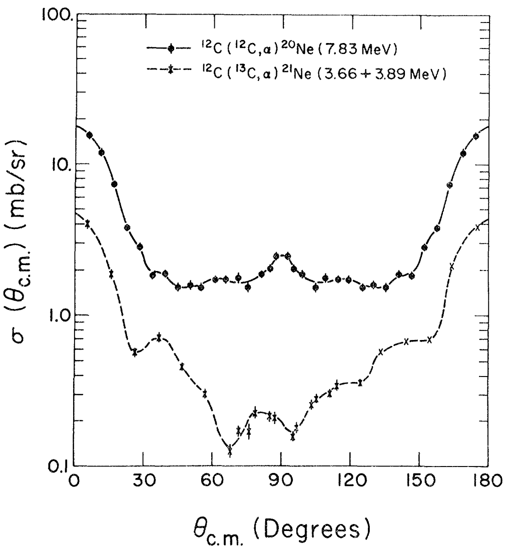

FIG. 3. The sum of the energy-averaged angular distributions for $^{12}C(^{13}C,\alpha)$ transitions to the 3.66- and 3.89-MeV levels of ^{21}Ne is compared with the angular distribution of the $^{12}C(^{12}C,\alpha)$ transition to the 7.83-MeV level in ^{20}Ne (Ref. 2).

citation function of the $^{12}C(^{12}C, \alpha)$ reaction.[2]]

The 7.83-MeV 2^+ state in ^{20}Ne has recently been found[2] to be of "quartet" configuration, and it has been suggested[3] that it is populated in the $^{12}C(^{12}C, \alpha)$ reaction by a direct plus semidirect reaction mechanism. Such reaction processes explain the selectivity of the reaction, the shapes of the angular distributions, and the presence of the broad resonances observed in the excitation functions of the $^{12}C(^{12}C, \alpha)$ data. The same processes would appear to be capable of explaining the features observed in the present work.

The spin and parity of the 3.66-MeV level is known[4] to be $\frac{3}{2}^-$, and that of the 3.89-MeV level has been limited[5] to $J=\frac{3}{2}$ or $\frac{5}{2}$. However, comparison with the level schemes of ^{21}Na and ^{23}Na strongly suggests[6] a $\frac{5}{2}^-$ assignment. Evidence favoring a $\frac{5}{2}$ assignment may also be inferred from the present work. The ratio of the integrated, energy-averaged differential cross section to the 3.66- and 3.89-MeV states is 1.46—very close to the $2J+1$ ratio of 1.5.

An interesting possibility is that the 3.66- and 3.89-MeV states of ^{21}Ne have the configuration of a $1p_{1/2}$ neutron coupled to the 2^+ member of the [220] quartet structure in ^{20}Ne, i.e., the 7.83-MeV 2^+ level of ^{20}Ne. Such a configuration would explain the selective population of these states in ^{21}Ne by the $^{12}C(^{13}C, \alpha)$ reaction. This possibility is further supported by the similarity between the summed $^{12}C(^{13}C, \alpha)$ angular distributions to the

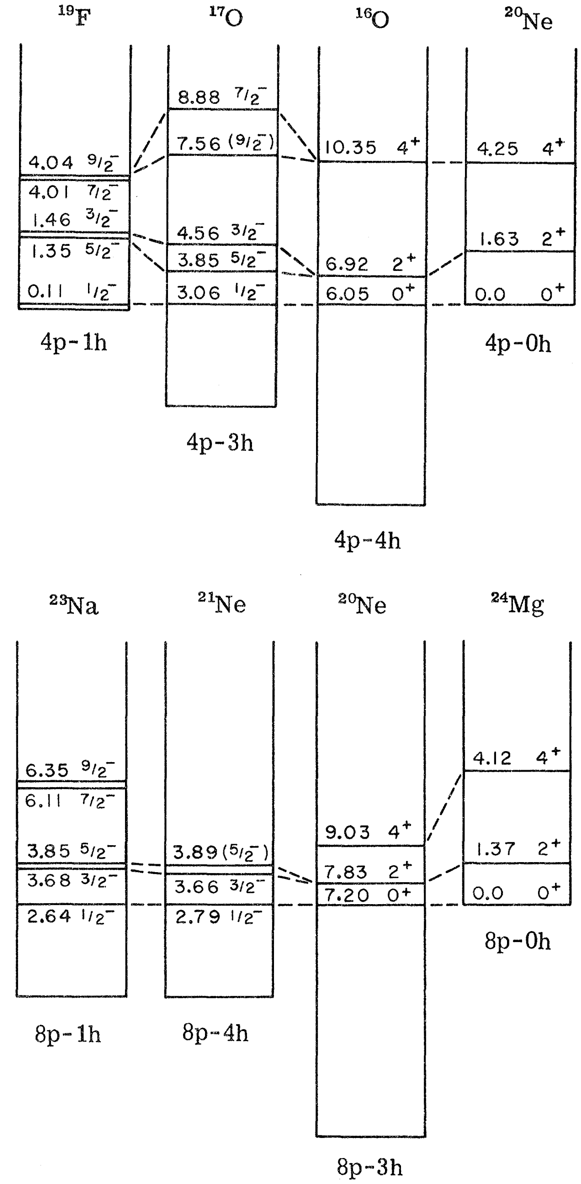

FIG. 4. Comparison of the weak coupling of 8p-nh levels with that of the 4p-nh levels.

3.66- and 3.89-MeV states of ^{21}Ne and that of the $^{12}C(^{12}C, \alpha)$ reaction to the 7.83-MeV level of ^{20}Ne, as shown in Fig. 3. At forward and backward angles, the summed cross sections are about one fourth that of the 2^+ state. A factor of 4 can arise as a consequence of the effects of identical particles in the entrance channel of the $^{12}C(^{12}C, \alpha)$ reaction.

The scheme of eight-particle, n-hole (8p-nh) levels in the weak-coupling model of sd-shell nuclei is compared with that of the 4p-nh levels[7] in Fig. 4. The identification of the 3.66- and 3.89-MeV levels in ^{21}Ne as a neutron weakly coupled to the 8p-4h 2^+ state at 7.83 MeV in ^{20}Ne is indicated. A state at 2.79 MeV in ^{21}Ne, which is thought[8] to have $J^\pi = \frac{1}{2}^-$, is tentatively identified as the $\frac{1}{2}^-$ member of this 8p-3h configuration. A few states between 6- and 8-MeV excitation in ^{21}Ne are also observed to be selectively populated by the ^{12}C(^{13}C, α) reaction and might be the $\frac{7}{2}^-$ and $\frac{9}{2}^-$ 8p-3h states.

In conclusion, the asymmetries observed[1] in the ^{12}C(^{13}C, α) angular distributions for the 3.66- and 3.89-MeV levels of ^{21}Ne persist over a wide range of incident energies. Furthermore, the angular distributions and excitation functions of the ^{12}C(^{13}C, α) reaction to the 3.66- and 3.89-MeV levels in ^{21}Ne are observed to be similar to those for the ^{12}C(^{12}C, α) reaction to the 2^+ member[2] of the 8p-4h ([220] quartet) configuration. This striking similarity suggests that the 3.66- and the 3.89-MeV states in ^{21}Ne may be the $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states of an 8p-3h configuration obtained from coupling a $1p_{1/2}$ neutron to the 2^+ [220] quartet state at 7.83 MeV in ^{20}Ne. At present, the question remains open as to the nature of the mechanism responsible for the fact that, in the ^{12}C(^{13}C, α) reaction, the angular distribution of the 3.89-MeV level is *forward* peaked, whereas that of the 3.66-MeV level is backward peaked.

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Bound-Pion Absorption by ^{12}C and Nuclear Short-Range Correlations*

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The absorption of stopped negative pions by ^{12}C inducing nucleon pair emission is studied. The three-body final-state scattering includes a two-body residual interaction and an optical potential. We find that agreement of this model with experiment cannot be obtained without including Jastrow-type short-range correlations with dominant momentum components between 0.3 and 0.4 GeV/c.

It is well known[1] that slow-pion absorption by nuclei favors the subsequent emission of a pair of fast back-to-back nucleons. The low momentum transfer ($\lesssim 25$ MeV/c) combined with the high-energy release ($\sim M_\pi$) is characteristic of a reaction designed to measure nuclear short-range pair correlations (SRC): The continuum nucleon pair wave with relative momentum $\frac{1}{2}|\vec{k}_1 - \vec{k}_2| \sim 350$ MeV/c serves as a probe of the matching momentum components in the bound-pair wave function.

Little if any conclusive direct evidence exists to date,[2,3] though, for the presence in nuclear wave functions of such high-momentum components in addition to those small ones already generated by the shell model (SM). As usual, the two basic ingredients of the SM are taken here to be a central Woods-Saxon potential of the independent particle model (IPM) and a residual two-body interaction[3] without repulsive core.

As a consequence of the impulse approximation and time-dependent perturbation theory, the pion absorption rate is given in terms of the matrix element of the standard nonrelativistic pion-nucleon pseudoscalar interaction taken between the bound and continuum nucleon pair states.[4] Pion