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Population of Resonant $^{12}C+^{12}C$ States via the Reaction $^{12}C(^{16}O, \alpha)^{24}Mg$

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Excitation functions for the reaction $^{12}C(^{16}O,\alpha)^{24}Mg$ have been measured from $E_{lab}(^{16}O) = 62$ to 110 MeV using a counter telescope at $\theta_{lab} = 7.5°$. Selective population of relatively few states at very high excitation energies in ^{24}Mg [$E_x(^{24}Mg) > 20$ MeV] is seen. A possible correspondence is found between these states and the narrow resonances reported in $^{12}C + ^{12}C$ reactions. In addition, a possible correspondence between averaged yields in $^{12}C(^{16}O,\alpha)^{24}Mg$ and gross structure seen in several $^{12}C + ^{12}C$ reaction channels is cited.

The reaction $^{12}C(^{16}O, \alpha)^{24}Mg$ has been studied extensively because of its striking final-state selectivity. It is interesting to consider whether this behavior reflects special structures in the initial, compound, and final systems. In this work we have significantly extended the $^{12}C(^{16}O, \alpha)^{24}Mg$ excitation functions. An apparent correlation has been found between individual pronounced transitions in that reaction and resonant states which have been seen in $^{12}C + ^{12}C$ reactions. Furthermore, the envelope of the $^{12}C(^{16}O, \alpha)^{24}Mg$ transitions shows a weak correlation with gross structure variations in the ^{12}C strength function as indicated by several $^{12}C + ^{12}C$ reaction-channel excitation functions.

High-resolution spectra from the reaction $^{12}C(^{16}O, \alpha)^{24}Mg$ were measured from $E_{lab}(^{16}O) = 62.0$ to 100.0 MeV in 1-MeV steps. Two measurements at $E_{lab}(^{16}O) = 105.0$ and 110.0 MeV were also taken. The experiment was performed at the Brookhaven National Laboratory Tandem Van de Graaff facility and employed a surface-barrier counter telescope placed at $\theta_{lab} = 7.5° \pm 0.25°$. Targets were nominally 45-$\mu g/cm^2$ natural carbon. The experimental resolution was typically 90 keV.

The primary objective of the study was to determine if the $^{12}C(^{16}O, \alpha)^{24}Mg$ spectra at higher energies show any gross- or fine-structure correlations to previously known ^{24}Mg states which have been observed via $^{12}C + ^{12}C$ resonance reactions. The α spectra contain numerous previously unseen transitions in the range of $E_x(^{24}Mg) = 20$ to 35 MeV—a region in which most $^{12}C + ^{12}C$ resonances have been recorded. The α-transition yields exhibit compound-nuclear fluctuations; to average out this effect and to enhance the persistently strong transitions, the spectra were averaged over the incident ^{16}O energy. This was performed by linearizing the 39 individual α spectra to a common ^{24}Mg excitation-energy scale. Kinematic corrections were performed so the energy-summed spectra would reflect center-of-mass cross sections. A smooth evaporative background was subtracted by hand from each spectrum to further enhance strong discrete transitions in the summed spectra. Figure 1 shows three typical linearized spectra and background curves. It is understood that the magnitude of the underlying

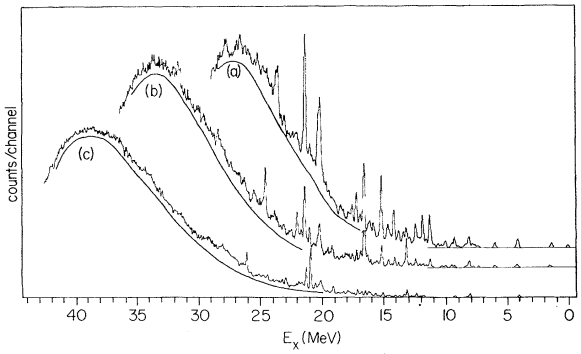

FIG. 1. Typical $^{12}C(^{16}O,\alpha)^{24}Mg$ spectra at $E_{lab} = 63$ (curve *a*), 77 (curve *b*), and 91 MeV (curve *c*). They have been linearized in $E_x(^{24}Mg)$ and the smooth curves are hand drawn to represent the background that is to be subtracted.

background cannot be known from this experiment and that the smooth curves subtracted here are subjective. Nevertheless, the quantities derived are a measure of the deviation of the spectra from a smooth background and should represent the strength of prominent states in this reaction.

Figure 2 shows the α-spectrum sum over the entire 62–100-MeV bombarding-energy range. Clearly, discrete states at high excitation energies in ^{24}Mg are populated strongly. A portion of the 62–100-MeV energy-summed ^{12}C(^{16}O, α)^{24}Mg spectrum is shown in Fig. 3 together with the calculated excitation energy in ^{24}Mg for the centroids of the stronger groups. Also included in the figure are the resonant energies and J^{π} values from ^{12}C(^{12}C, X) excitation functions of previous works.[1,2] The α transitions to states at E_x(^{24}Mg) = 25.5 and 28.5 MeV are possibly the same states as the prominent 8^+ and 10^+ resonances observed in the $p + ^{23}$Na channel at the same energies. The dashed lines suggest a plausible matching of the levels seen in our experiment and the resonances reported in the previously mentioned studies.

Any two sets of levels with comparable densities, in principle, could statistically exhibit a matching of the quality shown in Fig. 3. However, there is evidence that this is not merely a random alignment, and there are measurements that can be made to help determine whether the correlation is real. The ^{12}C + ^{12}C resonances can only be of even spin and parity, and have a preference for $J^{\pi} = 8^+$, 10^+, and 12^+ in this energy range.[1,2] It is unlikely, however, that every 8^+, 10^+, and 12^+ level has a large enough value of Γ(^{12}C) for it to be observed in a resonance reaction. On the other hand, if one assumes a statistical mechanism for the reaction ^{12}C(^{16}O, α)^{24}Mg, it is expected that both positive and negative natural-parity states in the $J = 6$ to 12 range should be

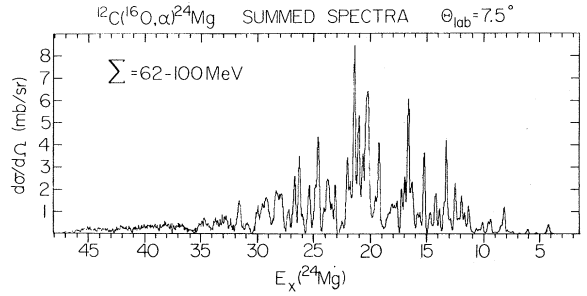

FIG. 2. α-spectrum sums, linearized in E_x(^{24}Mg). A smooth evaporative background has been subtracted from the individual spectra (see text).

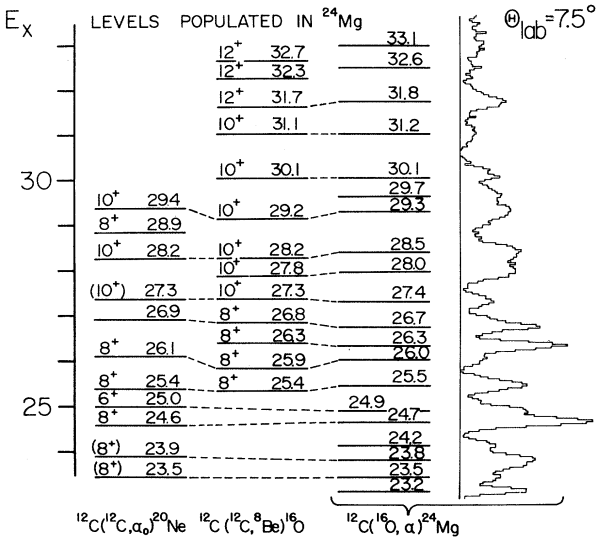

FIG. 3. Comparison of various experiments probing the ^{24}Mg compound nucleus. [Left histogram is excerpt from Fig. 1; ^{12}C(^{16}O,α)^{24}Mg energies taken from centroids of peaks in histogram.] ^{12}C(^{12}C,α) data from Ref. 1; ^{12}C(^{12}C,^{8}Be) data from Ref. 2.

populated strongly at this forward angle of θ_{lab} = 7.5°. Furthermore, by averaging the spectra over incident energy, an unbiased population of all states with these spins is expected. Yet, in spite of this large difference in the level densities accessible to the two reactions, the prominent states, or groups of states, appear to be at the same energies and of comparable number in both reactions. This suggests that there may be a structural relationship between the two reactions which lies outside simple selection rules. Several experimental tests of the level-matching hypothesis are possible. First, the spins of the prominent ^{12}C(^{16}O, α)^{24}Mg final states could be determined by an angular-correlation measurement of the subsequent particle decay of those final states themselves. The channels of interest would be $\alpha_0 + ^{20}$Ne, ^{8}Be + ^{16}O, or possibly ^{12}C + ^{12}C. The J^{π} assignments should agree with peviously reported values from ^{12}C(^{12}C, X) resonance reactions. Secondly, the magnitude of Γ_C for the prominent transitions from ^{12}C(^{16}O, α)^{24}Mg could be determined by measuring the $\alpha + ^{12}$C + ^{12}C breakup yield. If the level matching of Fig. 3 is correct, each of the ^{12}C(^{16}O, α)^{24}Mg transitions should have a carbon width which is consistent with the ^{12}C(^{12}C, X) resonance yields.

With the possible presence of a level matching, it becomes important to determine whether a correlation also exists between the envelope of the

$^{12}C(^{16}O, \alpha)^{24}Mg$ transition strength and the broader gross structures which have been recently reported in the $^{12}C + ^{12}C$ total-fusion-evaporation excitation functions.[3] Figure 4 compares a histogram of the reduced energy-summed $^{12}C(^{16}O, \alpha)^{24}Mg$ transition strength to the various $^{12}C + ^{12}C$ data and gives some indication that such a correlation does exist. Figures 4(d) and 4(e) representing the $^{12}C + ^{12}C$ elastic deviation function[4] and the $^{12}C + ^{12}C$ fusion-evaporation-residue cross section, show pronounced modulations of width $\Gamma \sim 2$ to 3 MeV which evince an approximate alignment with each other. Cormier *et al.*[5] have reported broad structure in the inelastic channels but the correlation to the elastic gross structure has not been established. As has been reported earlier,[6] such a matching of the broad elastic and fusion structure pointed out here is to be expected since the elastic deviation function measures departure from shape elastic scattering, and is thus a direct measure of $^{12}C + ^{12}C$ strength in ^{24}Mg. The cross section of fusion evaporation residues, which accounts for a major fraction of σ_{CN}, likewise reflects the $^{12}C + ^{12}C$ strength in ^{24}Mg, although missing components of σ_{CN} such as compound elastic and inelastic scattering. These anomalies are also in reasonable energy matching with the groups of 8^+, 10^+, 12^+, and 14^+ resonant states observed in the reactions $^{12}C(^{12}C, p)^{23}Na$ and $^{12}C(^{12}C, ^8Be)^{16}O$.[7,2] These data are shown in Figs. 4(c) and 4(b). Feshbach[8] has proposed that these cross-correlated groups are gross structures associated with the entrance channel $^{12}C + ^{12}C$. Finally in Fig. 4(a) is an average in $E_x(^{24}Mg)$ of the $^{12}C(^{16}O, \alpha)^{24}Mg$ spectrum in Fig. 2 where the ordinate is a sum of the yield in Fig. 2 over the range $E_x \pm 0.5$ MeV plotted every $E_x = 1$ MeV. There is a modulation in this graph with pronounced maxima at $E_x = 16$ and 20 MeV and weaker maxima near $E_x = 25$, 29, 33, and perhaps 38 MeV. It is known that the states near $E_x = 16$ MeV are mostly of $J^\pi = 8^+$, and it can be speculated that the group near $E_x = 20$ MeV corresponds to associated $J^\pi = 10^+$ states, being extensions of the low-lying ^{24}Mg rotational bands. It is tempting to relate the weaker maxima at the higher energies to the gross structures at the same energies seen in $^{12}C + ^{12}C$ reactions. This would imply a structural connection between the pronounced states seen in the reaction $^{12}C(^{16}O, \alpha)^{24}Mg$ and the broad $^{12}C + ^{12}C$ structures shown below. The origin of the latter broad structures is not fully understood but most likely arises from $^{12}C + ^{12}C$ shape resonances, possibly mixed with doorway

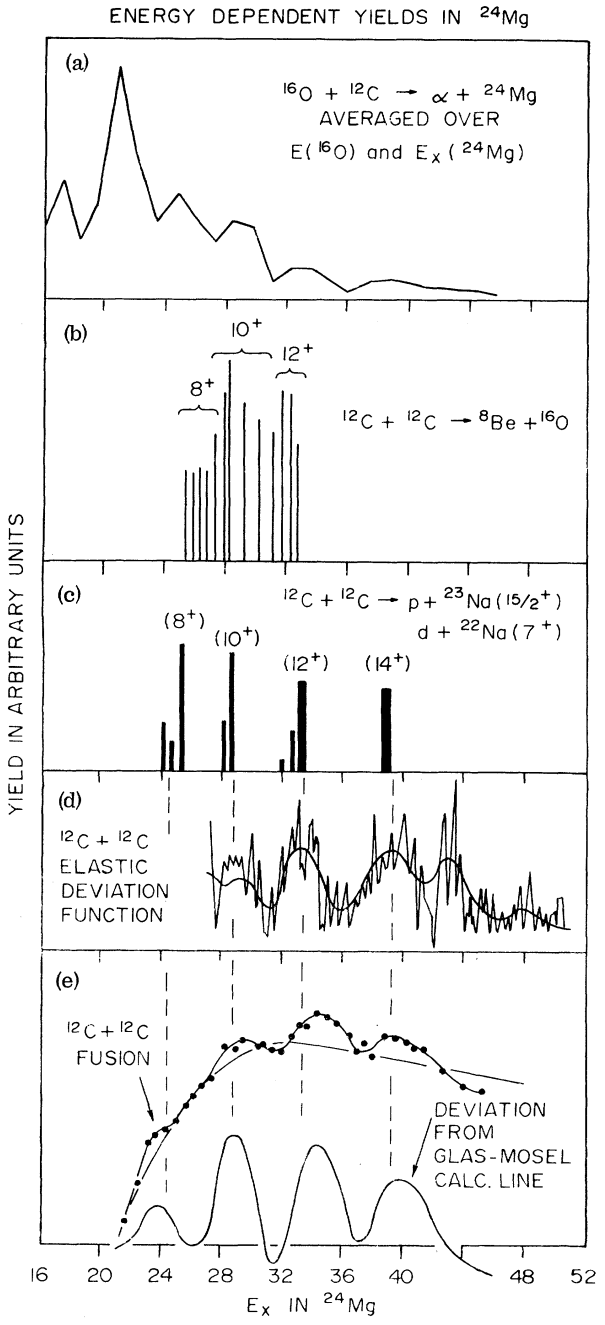

FIG. 4. Comparison of structures in various $^{12}C + ^{12}C$ exit channels and present data. (a) Present data; the line connects points representing the sum of data in Fig. 1 for $E_x \pm 1$ MeV plotted every 2 MeV in E_x. (b) Data from Ref. 2; heights represent strength of reported resonances (linear scale). (c) Data from Ref. 3; widths and heights represent widths and strengths of reported resonances (linear scale). (d) Data from Ref. 5; linear scale, no suppressed zero. (e) Data from Ref. 4; data presented with a suppressed zero, logarithmic plot; deviation of data from Glas-Mosel calculation is a linear plot with no suppressed zero.

states. The present result could be the first observation of such resonances as final states in a multiparticle transfer reaction and could prove new insights into the reaction $^{12}C(^{16}O, \alpha)^{24}Mg$ mechanism as well as the structure of the states in ^{24}Mg. Again a systematic study of the $^{12}C + ^{12}C$ decay following $^{12}C(^{16}O, \alpha)^{24}Mg$ population of these states would be an important extension of the present work.

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Elastic Electron Scattering from ^{3}He and ^{4}He at High Momentum Transfer

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Experimental values of ^{3}He (^{4}He) elastic structure functions up to momentum transfer $q^2 = 4.0$ (2.4) $(\mathrm{GeV}/c)^2$ are presented. They are compared to calculations using three- and four-body wave functions and to asymptotic models.

We present data on elastic electron scattering from ^{3}He and ^{4}He that extends the information from previous experiments[1] into the unexplored region of momentum transfer $q^2 > 0.8$ $(\mathrm{GeV}/c)^2$. This complements the large-q^2 measurements of electromagnetic structure functions already available for the dueteron[2] and may allow a better understanding of the failure of microscopic calculations[3-11] to explain existing data near $q^2 = 0.8$ $(\mathrm{GeV}/c)^2$. Large-q^2 data also will be important for an understanding of the asymptotic behavior of the structure functions. For example, in the dimensional-scaling quark model (DSQM), the structure functions at large q^2 are predicted[12] to decrease according to a power of q^2 determined by the number of elementary constituents. Of

