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Brief Reports

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Observation of $^{12}C+{}^{12}C$ resonances as final states in the $^{12}C(^{16}O,\alpha)^{24}Mg$ reaction

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Arguments based on recent level width and α branching ratio measurements are presented to show that $^{12}C+{}^{12}C$ resonances may not be populated by the $^{12}C(^{16}O,\alpha)^{24}Mg$ reaction as reported. Recent α spectra obtained at high bombarding energy are explained assuming ^{16}O projectile excitation followed by α emission.

[NUCLEAR REACTIONS $^{12}C(^{16}O,\alpha)^{24}Mg$, $E=60-100$ MeV, measured $\sigma(\theta)$, Γ, ^{24}Mg, deduced levels.]

In recent years, there has been moderate interest in the possibility that $^{12}C+{}^{12}C$ resonances may be observed as final states in the $^{12}C(^{16}O,\alpha)^{24}Mg$ reaction. Lazzarini *et al.*[1] presented results in the ^{24}Mg excitation range $E_x=20-30$ MeV from a moderate resolution counter experiment which they claimed as evidence of this phenomenon. More recently, Nagatani *et al.*[2] have made measurements on the $^{12}C(^{16}O,\alpha)^{24}Mg$ reaction at 145 MeV bombarding energy using an Enge split pole magnetic spectrometer to detect α particles. Broad peaks at α energies corresponding to high ^{24}Mg excitation energies ($E_x=27-56$ MeV, see Fig. 1) were attributed to exciting $^{12}C+{}^{12}C$ nuclear molecular resonance states. In the following we present arguments which suggest that the interpretations placed on the data of Refs. 1 and 2 are unfounded.

We have made measurements on the $^{12}C(^{16}O,\alpha)^{24}Mg$ reaction in the bombarding energy range of 60–100 MeV using the Brookhaven National Laboratory tandem accelerator MP7 as part of the study of high spin states in ^{24}Mg.[3] Using the quadrupole-dipole-dipole-dipole (QDDD) spectrometer at 0° and ~2 $\mu g\,cm^{-2}$ C targets, we determined or obtained upper limits for the widths of all strongly populated α groups. Alpha decay branching ratios for the ^{24}Mg states populated were also measured using a position sensitive surface barrier detector to observe coincidence α particles. A more complete discussion of all the results of this experiment will be published in a forthcoming paper. Only the results relevant to the present communication are presented here. The excitation energies and widths of the most prominent α groups observed in the present experiment are listed in Table I. All the strongly populated groups in our spectra up to 27.5 MeV excitation in ^{24}Mg were identified with levels reported in Ref. 1 by carefully comparing our spectra with spectra measured at the same energies by Cosman

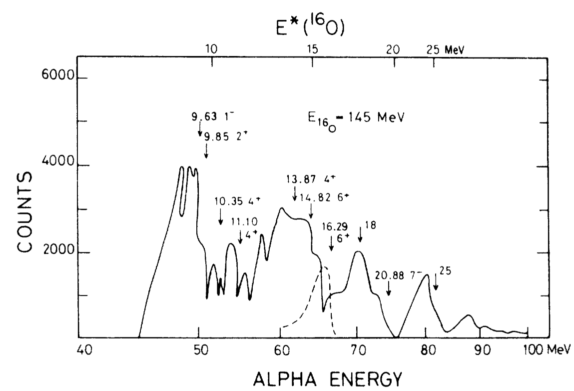

FIG. 1. Background subtracted α spectrum at 7° from the $^{12}C+{}^{16}O$ reaction (Ref. 2). The dashed curve is a calculated line shape assuming ^{16}O inelastic scattering followed by α decay. The arrows mark edges corresponding to excitation of ^{16}O into states at the indicated energies in MeV, given also by the upper scale. The level energies, spins, and parities are from Ref. 10.

TABLE I. Properties of prominent states in ^{24}Mg measured in this work.

E_x This work (MeV)	E_x Ref. 1 (MeV)	Γ (keV)	Branches to ^{20}Ne states (percent) 0.0 MeV (0^+)	1.63 MeV (2^+)	4.25 MeV (4^+)	8.78 MeV (6^+)	Others
22.93	23.2	62 ± 13		26	33		41
23.23	23.5	35 ± 13					
24.37	24.7	21 ± 7			63		37
25.18	25.5	163 ± 6		24	15	31	30
26.05	26.3	<13			8	65	27
26.45	26.7	115 ± 20				77	23

and Lazzarini.[4] The constant 300 keV difference between the two energy scales results probably from a systematic error in the calibration of Ref. 1.

The identification in Ref. 1 of states in ^{24}Mg seen in the ^{12}C(^{16}O, α)^{24}Mg reaction with resonances in the ^{12}C + ^{12}C system is based on a comparison with resonances observed in ^{12}C(^{12}C, ^{8}Be)^{16}O and in ^{12}C(^{12}C, α_0)^{20}Ne. The resonances reported in the ^{12}C(^{12}C, ^{8}Be) data[5] have $\Gamma \geq 200$ keV, whereas in most cases the level widths we determine (Table I) are $\Gamma \leq 70$ keV in the ^{24}Mg center of mass. These results clearly do not support the conclusion drawn in Ref. 1 that the ^{12}C(^{16}O, α)^{24}Mg reaction strongly populates the same states observed as ^{12}C(^{12}C, ^{8}Be)^{16}O resonances.

With respect to a possible relation with the resonances in the ^{12}C(^{12}C, α_0)^{20}Ne reaction, our results also show that all the strongly populated states in ^{24}Mg decay only weakly (< 10%) by α emission to the ground state of ^{20}Ne. Hence, it is unlikely that these states will be observed as strong resonances in the ^{12}C(^{12}C, α_0)^{20}Ne reaction. In fact, careful examination of the excitation function measured for the ^{12}C(^{12}C, α_1)^{20}Ne(2^+) angle-integrated cross section (Fig. 5 of Ref. 6) shows a single prominent anomaly, near 25.3 MeV excitation. Thus, the decay properties of the states seen in ^{24}Mg, as well as their widths, argue against the conclusion drawn in Ref. 1.

More recently, structures have been observed[2] in the spectrum of alpha particles from the reaction ^{12}C(^{16}O, α)^{24}Mg (see Fig. 1) in the range of excitation energies between 27 and 56 MeV. A correlation has been proposed between these structures and resonances in the ^{12}C + ^{12}C system. In this regard, we note that α groups observed in our position sensitive data have energy versus angle relationships that correspond to the kinematics for ^{16}O inelastic scattering (projectile excitation) followed by α decay to ^{12}C. Similar results have been reported by Wieland *et al.*[7] and Furuno *et al.*[8] who observed that, in the bombarding energy range of 68–80 MeV, the reaction proceeds through states at 10.35 MeV (4^+) and 14.82 MeV (6^+). Assuming this reaction to be present at the higher energies used by Nagatani *et al.*, then peaks would be expected to arise from kinematical considerations based on the fact that the angular distribution for inelastic scattering at high incident energies is strongly peaked at small center of mass angles. To test this idea, a peak shape was estimated for a ^{16}O 6^+ state at $E_x = 16.2$ MeV which α decayed to the ^{12}C ground state. The differential cross section for the ^{16}O inelastic scattering was calculated using the distorted-wave Born approximation (DWBA) code PTOLEMY.[9] The line shape we obtained exhibits a sharp upper edge and a fairly narrow width, which could result in structure similar to those observed in Ref. 2. The high energy edges to be expected for selected states in ^{16}O were also deduced using this line shape and are shown in Fig. 1. The shape of the tail depends only on the forward peaking of the inelastic scattering cross section, and it is evident from the present calculation that many of the peaks could be explained in terms of the reaction mechanism considered here. Furthermore, the result[2] that peaks with $E \sim 50$ MeV are not observed at $\theta_{lab} = 15°$ is consistent with the model. This arises because α particles emitted from states in ^{16}O moving forward at velocities appropriate to the 145 MeV incident energy are within a cone of half angle $\theta_{lab} < 15°$ for an excitation of ^{16}O ≤ 15 MeV.

The fact remains to be explained that the authors of Ref. 2 do not observe similar structures in the bombardment of a ^{13}C target. This could possibly be due to the enhanced inelastic scattering cross section arising from mutual excitation of the ^{16}O and the ^{12}C, a mechanism which is not available for ^{13}C + ^{16}O.

A comparison of intensities calculated in the model presented here with intensities measured in Ref. 2 would help to resolve this question. Unfortunately, such a comparison is not currently possible because no cross sections have been given in Ref. 2.

In conclusion, there is only weak experimental evidence that ^{12}C + ^{12}C resonance states are observed as final states in the $^{12}C(^{16}O, \alpha)^{24}Mg$ reaction at low bombarding energies. We have also presented an alternative interpretation of the existing data obtained at higher bombarding energies.

Note added in proof. Some of our conclusions have been corroborated recently by the work of W. D. Rea *et al.* [Phys. Rev. Lett. 45, 884 (1980)] who have observed that in the reaction of ^{16}O with $^{12,13}C$ nuclei at $E_{lab} = 140$ MeV, the α-^{12}C coincidence spectra is dominated by excitation and subsequent α decay of states in the projectile.

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