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KINEMATICS OF THE GROSS STRUCTURES IN THE α SPECTRUM OF THE $^{16}O + ^{12}C$ REACTION *

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A B S T R A C T

A kinematic analysis of broad peaks seen in the $^{12}C(^{16}O,\alpha)$ reaction is performed which demonstrates that contrary to previous speculations most of these structures are not states in ^{24}Mg. Structures with $E_x(^{24}Mg) \simeq 25$ and 28 MeV are identified as clusters of several narrow ^{24}Mg states.

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The inclusive α spectra observed in $^{16}O + ^{12}C$ reactions at high energy are known to exhibit a series of broad peaks on top of a very strong continuum. These peaks have recently been the subject of intensive experimental and theoretical study(1-8). The first observation of the structures at $E(^{16}O)$=145 MeV was reported by Nagatani et al.(1). They showed that the broad peaks have a close correlation in energy to the known $^{12}C + ^{12}C$ molecular resonances in ^{24}Mg and they speculated that they are excited in a direct 12-nucleon cluster transfer reaction $^{12}C(^{16}O,\alpha)^{24}Mg$. This interpretation was based on their measurements at $\theta_{lab}=7.5^o$ and 15^o which suggested a steeper than $(\sin\theta)^{-1}$ angular distribution although the statistical precision of the larger angle data and the rather small angular step make a definitive conclusion difficult.

Szanto de Toledo et al.(5) has considered a second mechanism in which the broad structures observed at $E(^{16}O)$=145 MeV are interpreted as clusters of narrow high spin states close to ^{24}Mg yrast line excited in the decay of a statistical ^{28}Si compound nucleus. This interpretation was supported by the observation that similar broad strutuctures become evident in the α spectra of the $^{12}C(^{16}O,\alpha)^{24}Mg$ reaction even at very low $E(^{16}O)$ when an explicitly beam energy and excitation energy averaged spectrum is constructed. Calculations fit to the very limited data available at high energy at that time suggested that the observed magnitudes of the broad peaks were not inconsistent with a compound nucleus mechanism.

A completely different interpretation of the broad structures was suggested by Branford et al.(6). They noted that sequential α decay of strongly forward peaked inelastically excited ^{16}O projectiles could produce broad structures in the inclusive spectrum for angles $\lesssim 25^o$. A key experiment along these lines was then performed by Rae et al.(7,8) who detected ^{12}C-α coincidences at $E(^{16}O)$=140 MeV. Their experiment was designed to detect the ^{12}C-^{12}C final state interaction expected if ^{24}Mg molecular states are formed as proposed by Nagatani et al. Their results were negative, no ^{12}C-^{12}C final state interaction was detected, rather the ^{12}C-α coincidence spectrum revealed only evidence for sequential α decay of inelastically scattered ^{16}O. Unfortunetely this result is not conclusive since it is readily possible that sequential α decay of ^{16}O is a significant component of the very strong α particle continuum in which case the ^{12}C-^{12}C residual interaction due to the much weaker peaks would be obscured.

Interest in molecular structure in ^{24}Mg persists now for two decades(9) it is therefore essential to ascertain whether a new spectroscopic tool for the study of these states has been discovered or whether one of the more trivial explanations is correct.

To address this question we have studied the energy dependence of the inclusive α spectra in $^{16}O+^{12}C$ reactions from $E_{lab}(^{16}O)$=94 MeV to 150 MeV. Theses measurement are pivotal in distinguishing the three reaction mechanisms discussed above: first they provide a stringent test of the reaction kinematics immediatly distinguishing between peaks in the spectrum due to sequential α decay of the projectile (following three body kinematics) and those due to ^{24}Mg final states, (following two body kinematics) and second the presence or absence of cross section fluctuations with beam energy tests the compound or direct nature of the reaction. Our results discussed below unambiguously demonstrate that the most prominent peaks in the α spectrum are <u>not</u> ^{24}Mg final states but rather exhibit kinematics charecteristic of sequential α decay of the projectile. Much weaker structures at $E_x(^{24}Mg) \approx 20$, 25 and 28 MeV are shown to exhibit the proper two body kinematics of ^{24} Mg final states.

structures are clearly composed of several much narrower ^{24}Mg states and that the cross sections for the narrow states fluctuate with beam energy revealing the importance of compound nucleus processes.

The measurements were performed using the ^{16}O beam from the Brookhaven National Laboratory 3 stage MP Tandem facility. Up to 1μA(elec.) beam intensity was available at terminal voltages of up to 16.25 MV. Alpha particles were detected in a standard silicon detector telescope at $\theta_{lab}=7.5^{0}$. Targets of 40 to 140 $\mu g/cm^2$ natural carbon (98.89% ^{12}C) were used and the excitation energy resolution varied from ~ 260 keV to ~600 keV.

Figure 1 shows a sample of background subtracted α spectra at various bombarding energies. The broad structures are clearly visible at all energies. The horizontal scale in Fig. 1 is excitation energy in ^{24}Mg and the vertical scale has been normalized to a beam current integrator and Target thickness and thus displays the relative cross section scale.

We wish to focus our attention on structures in the α spectra labeled A through H in Fig. 1. Figure 2 shows the apparent excitation energy of these structures in ^{24}Mg as a function of bombarding energy. The absolute excitation energy scale is accurate to ± 200 keV and the error bars in Fig. 2 include the uncertainty in the fitted peak position.

Structures A and B are identified as ^{24}Mg states at E_x=20.26 and 20.90 MeV respectively both of which have been assigned $J^{\pi} = 10^{+}$ in Ref.(10). These states are plotted in Fig. 2 to establish the validity of the α particle energy calibration at high E_{α}. Structure H on the other hand is a contaminent peak from the reaction $^{1}H(^{16}O,\alpha)^{13}N(gs)$. The solid line through the data points for this peak in Fig.2 was calculated for this contaminent reaction and the concurrence of the fitted peak positions with the calculation establishes the validity of the α particle energy calibration at low E_α.

The structures labeled E, F and G in Fig. 1 were identified by Nagatani et al.[1] as the (12^+), (14^+) and (16^+) members of the ^{24}Mg molecular band. Fig.2, to the contrary clearly indicates that these structures are not states in ^{24}Mg. The solid lines through the data for these structures in Fig.2 are calculated assuming inelastic projectile excitation to states in ^{16}O at E_x=23.1, 16.8 and 13.8 MeV at $\theta_{lab}(^{16}O^*)$=0 deg. The choice of this angle simulates the strong forward peaking of the inelastic angular distribution. Branford et al.[6] have shown that when proper account is made for the inelastic angular distribution an α particle line shape is predicted in good agreement with the observed peaks. The excitation energies in ^{16}O quoted above are associated with the centroids of the peaks in the α spectrum and thus should be regarded as approximate since the observed peak positions obviously depend somewhat on the actual inelastic angular distribution.

In their α -^{12}C coincidence measurement, Rae et al.[7] observed prominent sequential α decay of states in ^{16}O at E_x=15.8, 13.1, and 11.6 MeV. The higher two of these probably correspond to the structures G and F from Fig. 1. The α-peak due to a state in ^{16}O at 11.6 MeV would not be observed in our experiment.

The structures labeled C and D in Fig. 1 clearly exhibit kinematics of the $^{12}C(^{16}O,\alpha)^{24}Mg$ reaction in Fig. 2. A detailed view of this region of excitation energy is provided in Fig. 3. Noting particularly those runs in which a thin target was used ($E(^{16}O)$=129, 132, 145 and 150 MeV) we observe that both of the structures are composed of several narrower states. The intensities of the individual component peaks fluctuate rather strongly with

energy thus suggesting the dominance of a compound nucleus mechanism. We have investigated these states further in a separate experiment at $E(^{16}O)$=97 MeV in which a magnetics spectrograph was used to detect the α particles with a resolution of $\Delta E_x \leq$ 100 keV. The results of this experiment will be reported in detail elsewhere, but we mention two points of relavance here. First, the total widths of the component peaks are ≤ 100 keV and second detailed angular distributions display less anisotropy than $(\sin\theta)^{-1}$. The first point precludes the molecular resonance hypothesis in connection with the broad peaks and the second point strongly supports the compound nucleus mechanism.

In conclusion, a study of the energy dependence of the inclusive α-spectra of the ^{16}O +^{12}C reaction unambiguously reveals that the dominant broad peaks in the spectrum do not follow two-body kinematics but rather have kinematic properties of sequential α decay of the projectile. Two, much weaker broad structures are observed which appear to be composed of several considerably narrower ^{24}Mg states. The energy dependence and angular distributions of these states suggest a compound nucleus process.

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FIGURE CAPTIONS

FIG.1 - A sample of the background subtracted α spectra observed at several bombarding energies. The horizontal scale is excitation energy in ^{24}Mg and the vertical scale is the Laboratory system cross section in arbitrary unity. Several structures labeled A through H are identified for discussion in the text.

FIG.2 - Apparent excitation energy in ^{24}Mg for structures identified as A through H in Fig.1. Plotted versus bombarding energy. The solid lines through the data were calculated as discussed in the text.

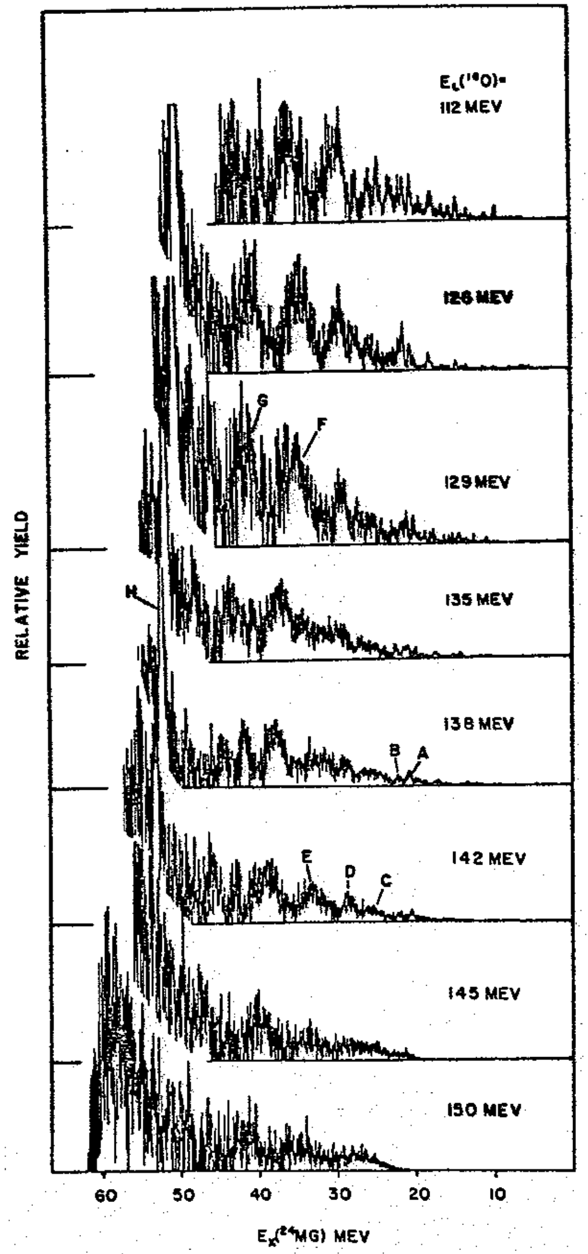

Figure 1

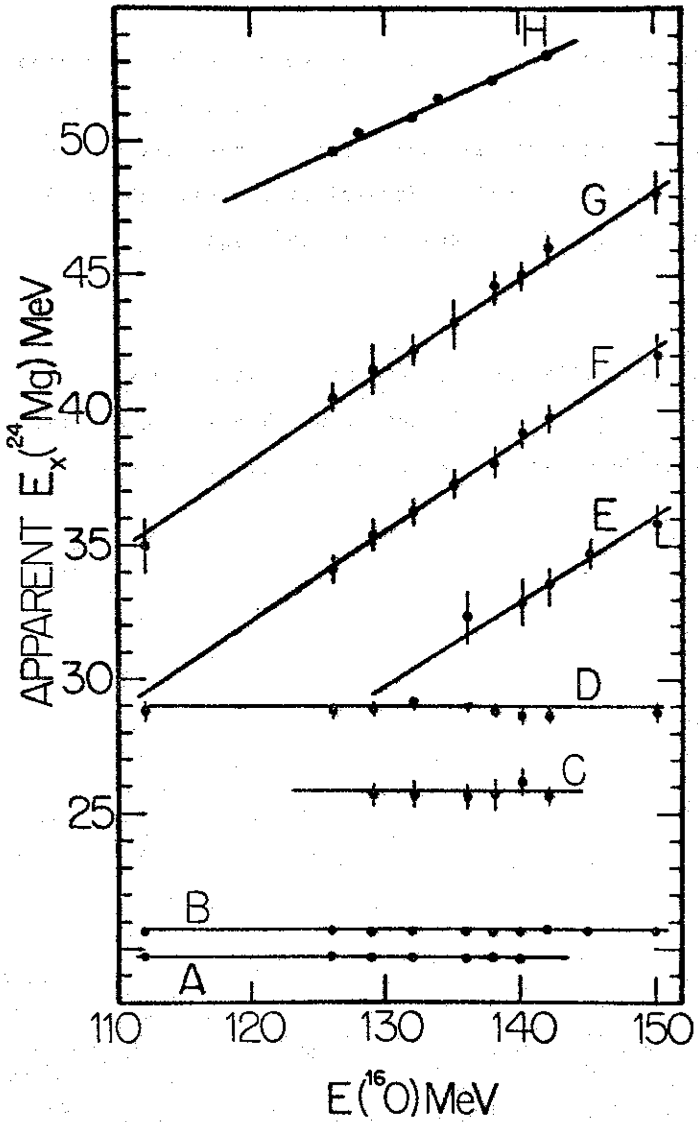

Figure 2