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BRIEF REPORTS

Brief Reports are short papers which report on completed research or are addenda to papers previously published in the **Physical Review.** *A Brief Report may be no longer than four printed pages and must be accompanied by an abstract.*

New $T = 0$ strength in ^{16}O at E_x=24 to 27 MeV

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There are several known $T = 1$ states in ^{16}O in the region of 24 to 27 MeV excitation. We observe the alpha-particle decay to the ground state of ^{12}C of many excited states in ^{16}O, some of which reside between 24 and 27 MeV. Either we have observed new states in ^{16}O or there is a very strong admixture of $T = 0$ in these previously assigned $T = 1$ states.

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A search for high spin alpha-particle cluster resonances in ^{16}O has resulted in the discovery [1] of a broad $J^\pi = 8^+, 9^-$ resonance at 29.9 MeV excitation, but has not revealed evidence for the long sought 8^+ state predicted by various alpha-particle models [2] at somewhat lower excitation. The reaction used, ^{12}C(^{12}C,^{16}O* $\rightarrow \alpha+^{12}$C)^{8}Be at 120 MeV bombarding energy, also did not reveal any appreciable strength for ground state alpha-particle decay of ^{16}O excited between 23 and 28 MeV. The states of ^{16}O were observed by kinematic reconstruction of coincidence events in which the positions and energies of both the alpha-particles and the ^{12}C particles were measured.

We have made a similar measurement but using the entrance channel of ^{7}Li + ^{12}C with a carbon bombarding energy of 90 MeV. Although the present reaction has $T=\frac{1}{2}$ in both entrance and exit channels, our data present evidence for major new $T = 0$ strength. The detection setup was the same as used in an investigation of the decay of ^{15}N* [3] except that the 5 cm long position sensitive alpha-particle detector and the position sensitive particle identifying telescope were at laboratory reaction angles of plus and minus 20°, on opposite sides of the ^{12}C beam. The 5 cm long detector spanned an angular range in the reaction plane of about 27° while the 1 cm diameter telescope spanned about 5°. The time resolution for the coincidence was sufficient to determine that the particles were emitted within a single beam pulse of the Florida State University Tandem/LINAC accelerator. In our reaction, ^{7}Li(^{12}C,^{16}O* $\rightarrow \alpha+^{12}$C)t, the momenta of the two detected particles are used to calculate that of the third, and hence a Q-value spectrum can be calculated based on the assumption that the particle in coincidence with the identified ^{12}C is an alpha particle and that there are only three particles in the final state. Such a spectrum generated for the present experiment is shown in Fig. 1.

The vertical arrows in Fig. 1 indicate the positions of known Q values of some multiparticle final state reactions with a ^{7}Li + ^{12}C entrance channel. The shaded region shows the approximate Q-value range of a gate used to identify the events for which decay energies for ^{16}O $\rightarrow \alpha_0$ + ^{12}C(g.s.) were calculated. The background under this peak of interest can be a combination of accidental coincidences, spontaneous breakup of ^{7}Li, and, since there is no particle identification in the 5 cm long detector, we allow a background of coincident events between a ^{12}C and either t, d, or p which would be treated as ^{12}C + α events in the kinematic analysis. The large broad maximum on the right of the figure is undoubtedly a combina-

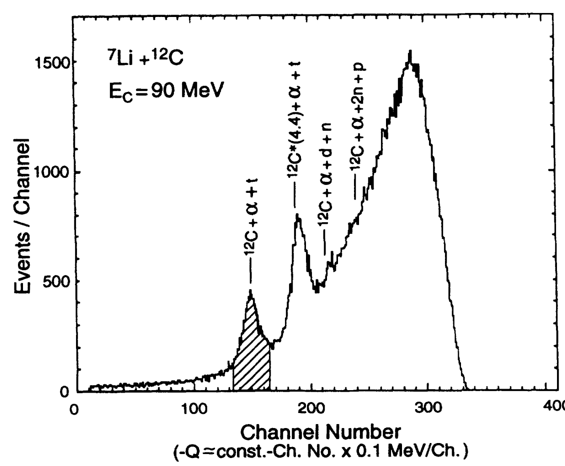

FIG. 1. Negative Q-value spectrum based on the assumption that the reaction is ^{7}Li+^{12}C$\rightarrow^{12}$C+α+t and that the particles detected in coincidence are ^{12}C and α.

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tion of these background components and the four-body and five-body channels which open as indicated. In contrast to the work of Rae *et al.* [1], alpha-particle decay to the first excited state of ^{12}C at $\sim$4.4 MeV did not significantly indicate states in ^{16}O in the excitation energy region of interest.

A spectrum of the calculated relative energies ($E_{\rm rel}$) between the two particles detected in coincidence, for the events in the shaded region of Fig. 1, is shown in Fig. 2. Except for the peaks labeled at excitation energies of 24.9 MeV and 26.8 MeV, all peaks have corresponding energies which agree with values tabulated by Ajzenberg [4] which also gives the J^π values indicated in Fig. 2. The two unexpected peaks are in a region of the ^{16}O* spectrum which contains eight "known" [4] $T = 1$, natural parity states, between 24 and 28 MeV excitation, yet states are prominently observed here in a $T = 0$ decay channel. The single $T = 0$ state in this region, at 24.36 MeV [4], is well below the 24.9 MeV peak shown in Fig. 2. The detection threshold dictated by our detector geometry is near $E_x = 10$ MeV. The effective solid angle for ^{16}O*(E_x) detection between $E_x = 18$ and 30 MeV is nearly constant, varying from 1.5 to 1.2 msr. The great decrease in yield at higher excitation is because of a kinematic reduction of the cross section and not because of lack of detection efficiency.

The excitation near 25 MeV has also been observed in the $T = 0$ entrance and exit channel reaction, ^{12}C+^{12}C$\to$ α+^{12}C+^{8}Be, with the yield less than but comparable to other $T = 0$ states, although with quite poor statistics [5]. It was also found advantageous in that work to consider the scatter plots of $E_{\rm rel}$, for the particle pair of interest, vs the $E_{\rm rel}$ of other pair combinations in the three-body final state. In the present case, scatter plots of $E_{\rm rel}$(^{16}O$\to$ α+^{12}C) vs $E_{\rm rel}$(^{7}Li$\to$ $\alpha + t$) and of $E_{\rm rel}$(^{16}O$\to$ α+^{12}C) vs $E_{\rm rel}$(^{15}N* $\to$ t+^{12}C) do not indicate that specific excitations regions of ^{7}Li, decaying by alpha-particle emission, or of ^{15}N, decaying by triton emission, are contributing to a background at high excitation in the ^{16}O decay spectrum.

We have been able to enhance the resolution in $E_{\rm rel}$ spectra by judicious cuts in the angular phase space of the sequential binary decay process. The angles, measured between the decay axis and the beam axis, are $\theta_{\rm c.m.}$ for the first decay pair, ^{16}O*+t, and ψ_Z for the second decay pair, ^{12}C+α. Such a spectrum is shown in Fig. 3. The background above channel 100 is indicative of contributions from improperly identified events and accidental coincidents, since the yield of ^{16}O excited to states above 17 MeV is limited by our detector geometry to smaller c.m. angles given by the approximate empirical equation $\theta_{\rm c.m.} \sim 72° - (E_x - 7.16){\rm MeV} \times 2.8°/{\rm MeV} \pm 10°$. Several well known [4] alpha-decaying states appear in Fig. 3 which were not apparent in Fig. 2. It is interesting to note that all states observed for which the isospin is known have the value $T = 0$. The spectrum, which shows a system resolution of $\lesssim$300 keV, also shows the known widths of broad states at 11.60, 14.66, and 16.27 MeV. In fact the J^π=5$^-$, Γ=670 keV [4] state must be dominant in the 14.7 MeV peak due to the observed width, and the broad 3$^-$ state at 15.83 MeV, $\Gamma \simeq$700 keV [4] has a clear contribution to the highest energy peak of this spectrum as evidenced by the low energy shoulder on this peak.

Selection of $\theta_{\rm c.m.}$ regions does not reveal any high energy states other than those seen in Fig. 2, with the exception of a peak presumed to represent the known [4] high spin triplet near 21.7 MeV. Selection of a small region of alpha-decay angle, however, does improve slightly the peak to background ratio, as illustrated in Fig. 4. A significant feature of this spectrum is not the states observed but rather those which are not observed. There are five known [4] natural parity, $T = 1$, states between 17 and 19.3 MeV excitation, and a possible $T = 1$, J^π=1$^-$ state at 23.2 MeV. None of these states, which would appear in low background regions of the spectra, are observed and attempts to enhance their observation with angular phase space gates have proven unsuccessful. Also it is interesting that a proposed state [6] with $T = 0$, J^π=8$^+$ at 22.5 MeV is absent. Since we observe the α_0 decay of all known unbound members of the

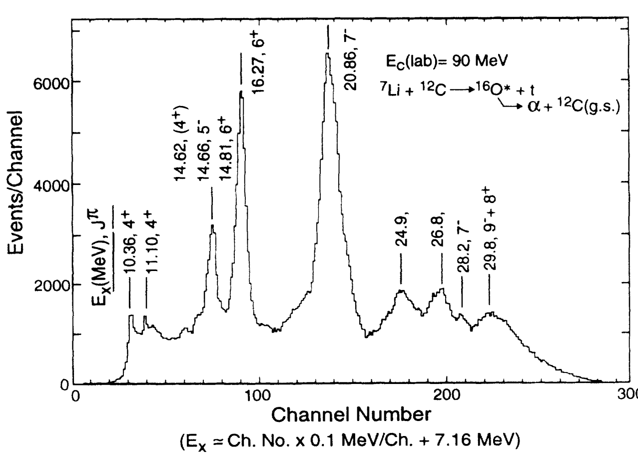

FIG. 2. Decay energy ($E_{\rm rel}$) spectrum for ^{16}O* $\to$ α_0 +^{12}C(g.s.), for the entire angular phase space of our detector geometry. Decay energy is given by channel number times 100 keV/channel.

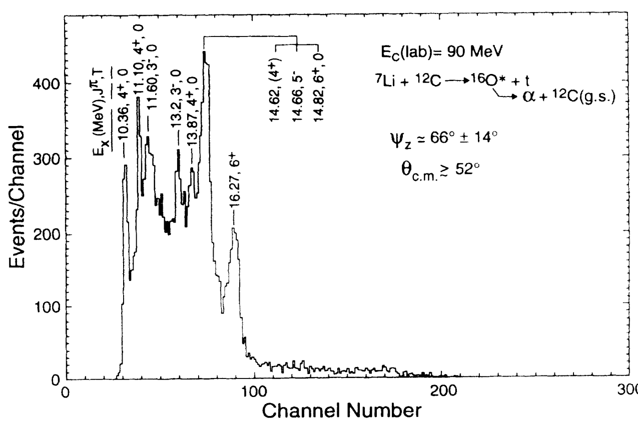

FIG. 3. Decay energy spectrum for a region of angular phase space selected to enhance the resolution and observability of states in ^{16}O below 17 MeV in excitation. All states observed with known isospin have $T = 0$.

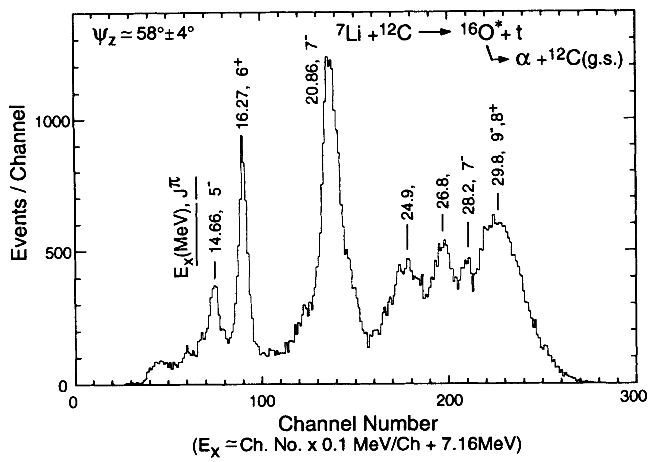

FIG. 4. Decay energy spectrum for ^{16}O* for a decay angular range selected to enhance the yield to background ratio at high excitation.

$K^\pi=0^-$ alpha-cluster band, $J^\pi=3^-$–9^-, and also of the $K=0^+$, four-particle–four-hole (4p-4h) band, $J^\pi=4^+$ and 6^+, it is unlikely that an 8^+ member of that band at 22.5 MeV would fail to appear in a region of such low yield.

A number of high spin states have also been observed [7,8] in the alpha-particle transfer reactions ^{12}C(^{6}Li,d)^{16}O* by measuring the deuteron in coincidence with the α_0 decay of ^{16}O*. Those states [7] with E_x, J^π = 20.9 MeV, 7^- and 21.7, 6^+ are also observed in the current study (the latter not shown). However, the states [8] with E_x, J^π = 23.6 MeV, 6^+ and 27.7 MeV, 7^- are not observed although their strength could be buried in the continuum of our observed yield. The work of Artemov *et al.* [8] shows little excitation of ^{16}O between those energies of 23.6 and 27.7 MeV where we see a major contribution.

In our experiment, the states which are labeled 24.9 and 26.8 MeV are observed with about the same angular phase space with which Rae *et al.* [1] observed the 29.8 MeV state, from which they established spin information from the slope of observed maximum cross sections in the ψ_z vs $\theta_{\rm c.m.}$ plane. That type of model-independent analysis is unavailable to us because of the nonzero channel spin and because of the absence of well isolated resonant states. These states, at 24.9 and 26.8 MeV, appear to have widths of $\Gamma \sim 1$–2 MeV; however, the measurement of partial decay widths by the method cited earlier [3] cannot be applied here for three reasons: The states are not sufficiently isolated, the production cross sections for these states have not been observed, and the angular range observed ($\Delta\psi_z \sim 50°$) would be inadequate for properly integrating the double differential cross section.

Although we cannot determine spins or partial decay widths, the evidence clearly indicating that these states are primarily $T = 0$ is based on three important observations. Except for this energy region, all states observed which have a known isospin have $T = 0$; however, lower energy $T = 1$ may have insufficient $T = 0$ strength to be observed in $T = 0$ decay. We observe this energy region with strength comparable to that of known $T = 0$ states. And last, even in the two-body reaction, where $T = 1$ population is allowed, no $T = 1$ states in the ^{12}C(^{7}Li,t)^{16}O* reaction have ever been observed [9]. We conclude that either we have evidence for two new $T = 0$ states in ^{16}O, or that the states tabulated in this energy region to have some $T = 1$ strength are primarily $T = 0$. There is recent evidence [10] of $J^\pi = 6^+$ and 7^- strength in the energy region 24–27 MeV based on a careful analysis of the $T = 0$ reaction of Rae *et al.* [1] although no identifiable resonant states were observed. The $T = 1$ assignments in this region are based primarily on observation of γ rays from a $T = 1$ state in ^{12}C* following the alpha-particle decay of ^{16}O* formed in a resonance reaction [11]. Such a method could be very sensitive to small admixtures of $T = 1$, whereas the current comparative yields argue for a major admixture of $T = 0$. Not only do the excitations at 24.9 and 26.8 MeV have a major $T = 0$ component and natural parity, but also from the systematics of other states observed in this study we would presume these states to have high spin (≥ 6) and to have large alpha-particle decay widths ($\Gamma_\alpha/\Gamma \gtrsim 30\%$).

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