SELECTIVE POPULATION OF HIGHLY EXCITED STATES OBSERVED IN THE REACTION $^{16}O(^{12}C, \alpha)^{24}Mg$*†

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The reaction $^{16}O(^{12}C, \alpha)^{24}Mg$ has been observed to populate states at E_x=16.30, 16.55, and 16.84 MeV with center-of-mass cross sections (at $\Theta_{c.m.}$=11°) of 1.8, 4.5, and 4.1 mb/sr, respectively. The evidence suggests that these states possess high angular momentum. Another state observed at E_x=15.15 MeV could be the $J^\Pi=9^+$ member of the $K=2$ rotational band.

The present Letter reports preliminary results of a program of high-resolution studies of heavy-ion-induced reactions that is currently in progress at the University of Pennsylvania. For this work an unusual gas target[1] was developed for use with the multiangle spectrograph. The feature that makes this gas target particularly suited for heavy-ion studies is that it has no entrance window and is thus able to withstand intense heavy-ion bombardment. Other advantages of a gas target are the accurately known target thickness and the freedom from the usual target impurities. In the present study of the reaction $^{16}O(^{12}C, \alpha)^{24}Mg$ performed at an incident energy of 36 MeV, the cell pressure was maintained at 5.0 Torr—corresponding to a target thickness of 8.5 $\mu g/cm^2$.

The motivation for this study was to search for high angular momentum states in ^{24}Mg. These states would be expected to have small widths and appear as narrow groups superimposed on a smooth background due to broad states and to the three-body continuum. An alpha-particle energy spectrum, spanning an excitation-energy range of 14 to 22 MeV in ^{24}Mg, is shown in Fig. 1. The most striking features of this spectrum are the three prominent narrow groups at 16.30, 16.55, and 16.84 MeV (energy uncertainty ±25 keV), and

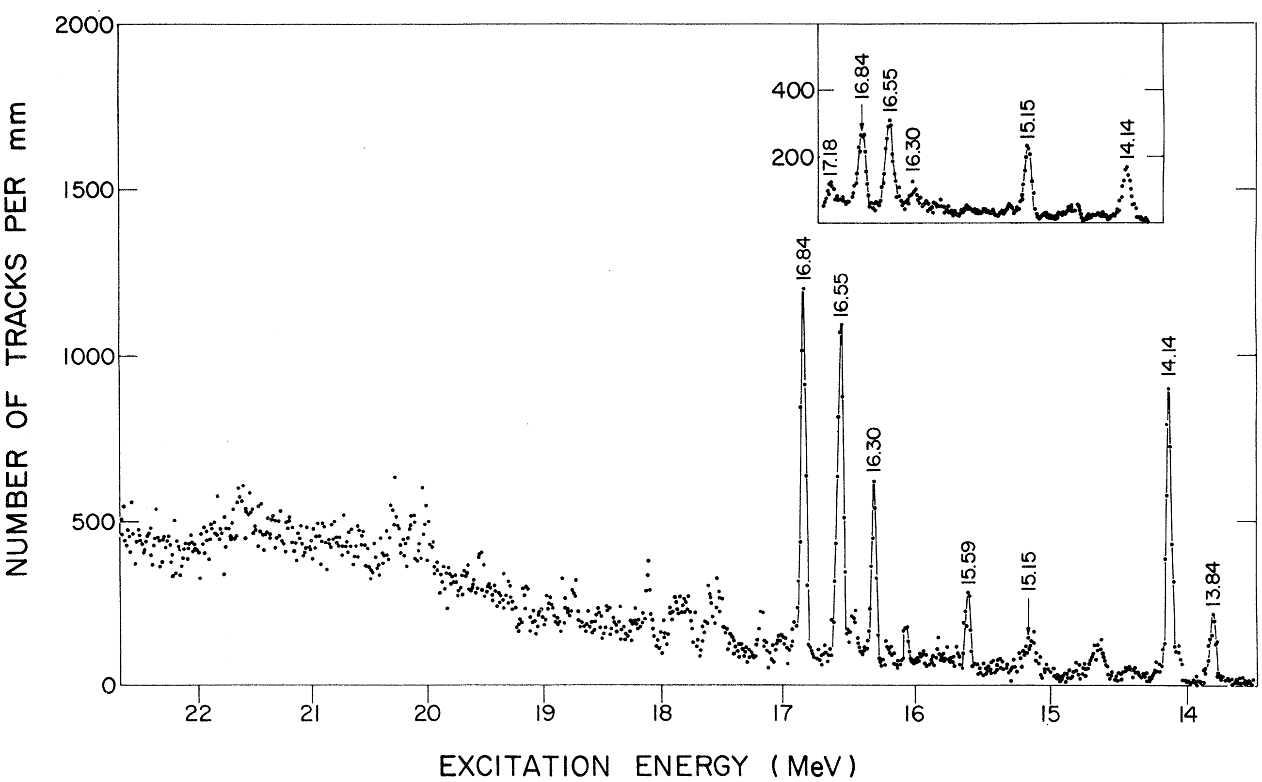

FIG. 1. Alpha-particle spectrum for the reaction $^{16}O(^{12}C, \alpha)^{24}Mg$ at a bombarding energy of 36 MeV and a lab angle of 7.5°. The inset shows a limited energy spectrum obtained at a lab angle of 45°.

the almost complete absence of groups at higher excitation energies. The full widths at half-maximum (FWHM) of the groups at 16.30 and 16.84 MeV were measured to be 45 ± 3 keV which is within the errors of the estimated experimental resolution. This is consistent with an actual width $\Gamma\lesssim 20$ keV. The group at 16.55 MeV is 5 to 10 keV wider. Analysis of the line shape suggests that this group could be a doublet, the weaker member lying at $E_x\cong 16.57$ MeV and having a peak cross section of about 20% of that for the 16.55-MeV state.

Angular distributions of these and three other prominent states are presented in Fig. 2. The absolute cross sections were calculated from the known geometry of the gas cell, the pressure, and the integrated charge. Because of uncertainty in the charge state of the primary beam after traversing the target, an uncertainty of ±25% is assigned to the absolute cross section. It is striking that the differential cross sections of the three states near $E_x = 16.5$ MeV are extremely large (a few millibarns per steradian) at forward angles.

With the exception of the state at 15.15 MeV, all of the angular distributions are of a similar shape—exhibiting a forward peak and a smooth falloff toward larger angles. The forward minimum for the 15.15-MeV state is suggestive of unnatural parity.[2] This state is possibly the 9^+ member of the $K=2$ rotational band based on the 4.23-MeV 2^+ state. Akiyama, Arima, and Sebe[3] predict such a state to lie near $E_x = 16$ MeV.

The nature of the three strongly excited states near 16.5 MeV is at present obscure, and it is evident that much further work is necessary for a complete understanding of it. For example, it would be of interest to study the decays of these states and to make particle-particle or particle-γ angular-correlation measurements. Also, excitation functions of the cross sections leading to these states should help to determine whether they are related to a specific resonance in a compound system. Some information concerning the energy dependence for the formation of these states is available from a study of the reaction

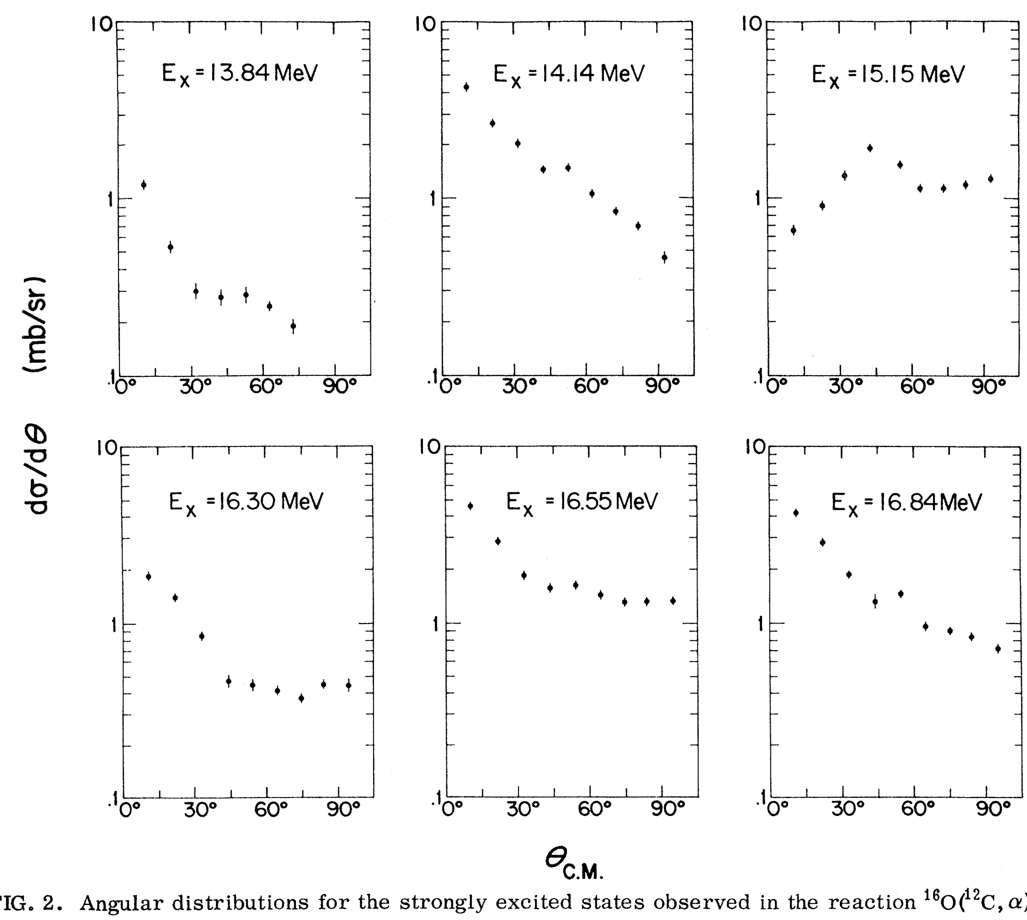

FIG. 2. Angular distributions for the strongly excited states observed in the reaction $^{16}O(^{12}C,\alpha)^{24}Mg$.

$^{12}C(^{16}O, \alpha)^{24}Mg$ performed in this laboratory at a bombarding energy of 36 MeV. This incident energy corresponds to a center-of-mass energy of 15.4 MeV compared with $E_{c.m.}$=20.6 MeV when the ^{12}C beam was used. At the lower c.m. energy these three states were not strongly excited. However, in the reaction $^{12}C(^{16}O, \alpha)^{24}Mg$ studied very recently at Yale[4] at $E_{c.m.} \approx 20$ MeV, these three states were strongly excited.

States in ^{24}Mg are unbound with respect to neutron decay above 16.53 MeV, to ^{12}C decay above 13.93 MeV, to proton decay above 11.69 MeV, and to alpha-particle decay above 9.32 MeV. The small widths ($\Gamma \lesssim 20$ keV) for the three states near 16.5 MeV could be explained if they had high angular momentum or if they were composed of unusual configurations. (For example, if they were of a $^{12}C + ^{12}C$ molecular nature, their decay would be strongly inhibited.) The most likely decay mode would appear to be alpha-particle emission. Calculations of alpha-particle penetrabilities suggest that, for the states in question, $\Gamma \lesssim 20$ keV corresponds to $J \geq 7$. Additional evidence that the reaction $^{16}O(^{12}C, \alpha)^{24}Mg$ strongly populates high-spin states is the large cross section observed for the state at 14.14 MeV. This state is known[5] to be the 8^+ member of the $K=2$ rotational band. An interesting possibility is that one of the three states around 16.5 MeV is the 10^+ member of the ground-state rotational band which has recently been predicted[3] to lie near 17 MeV excitation.

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$E1$ TRANSITIONS FROM THE SEPTUPLET IN Bi^{209}

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$E1$ transition rates from the septuplet of Bi^{209} are analyzed using a simple model in which a direct coupling between the octupole and the dipole states of the core nucleus Pb^{208} is taken into account. It is shown that by using reasonable parameters one can get results which are consistent with the observed decay rates.

Recently many studies[1] have been made for the nuclei around Pb^{208} to explore the validity of the particle-vibration coupling model. Hamamoto[2] investigated the decay scheme of the septuplet of Bi^{209} on this model and her predictions were proved to be in good agreement with the experimental data.[3-5] Especially, the agreement for the $E1$ transitions is remarkable. Broglia et al.[5] also made the analysis of their experimental data based on the particle-vibration coupling model. In the calculation of Ref. 2 various single-particle states which are admixed with the members of the septuplet were taken into account, and the same dipole effective charge was assigned to all those particle states. In Ref. 5, on the other hand, the particle-dipole vibration and the particle-octupole vibration couplings were taken into account, and the dipole effective charge was not used. It is expected that the latter approach will give similar results to the former approach if the calculation is made accurately.

The purpose of the present note is to present a simple method which enables us to calculate the transition rates quickly. The six graphs shown in Fig. 1 correspond to the fundamental transition processes from the septuplet member $|(j_1, 3^-)J_1\rangle$ to a final single-particle state $|j_3\rangle$. The wavy lines are used for the vibrational states and the dotted line is for the $E1$ transition. The intermediate state $|j_2\rangle$ can also be depicted as a hole state (a backward-going line), but such