Knockout of Heavy Clusters from $^{24}Mg_{(g.s.)}$

B. N, Joshi, Arun K. Jain, D. C. Biswas, B. V. John, Y. K. Gupta, L. S. Danu, R. P. Vind, G. K. Prajapati, A. Saxena, A. Chatterjee, and K. Ramachandran
Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA

The $^{24}Mg_{(g.s.)}$ nucleus as well as its low lying states have been theoretically described well in terms of the shell model in the full $(sd)^8$ space as well as $^{12}C+^{12}C$ and $^{16}O+^{8}Be$ cluster structures [1, 2]. In the high density interior region all these three descriptions overlap well due to the non-orthogonality of their descriptions. In the surface region however, the $^{12}C+^{12}C$ and $^{16}O+^{8}Be$ cluster descriptions score better because of the cluster bindings as well as increased average surface matter density. Experimentally there is no confirmation of superiority of one model over the other. For the excited states of ^{24}Mg however, experimentally it is seen that they preferentially decay through two ^{12}C's either in their ground state or low lying excited states [1].

In this paper we report our work on the heavy cluster knockout, $^{24}Mg(^{12}C,2^{12}C)^{12}C$ and $^{24}Mg(^{12}C,^{12}C^{16}O)^{8}Be$ reaction experiments and their finite range (FR)-DWIA analyses [3, 4]. The experiments were performed at the BARC-TIFR Pelletron LINAC facility using 104 MeV 3.5 pnA ^{12}C beam on 400 $\mu g/cm^2$ natural Mg target at four symmetric angle pairs ($\theta_1 = \theta_2$ 40.5^o, 36.7^o, 33.9^o, 49.6^o). The angle pair $\theta_1 = \theta_2 = 40.5^o$ kinematically contains the zero recoil momentum (q_R) condition for the $^{24}Mg(^{12}C,2^{12}C)^{12}C$ reaction at 104 MeV. The choice of incident energy and the angle pairs is such that the three angle pairs ($\theta_1 = \theta_2 = 40.5^o$, 33.9^o, 49.6^o) avoid the ^{24}Mg resonances which primarily decay by two ^{12}C's in their g.s. or in their excited states at the minimum q_R permissible. However the angle pair $\theta_1 = \theta_2 = 36.7^o$ peaks at the 14^+ state of ^{24}Mg. The summed energy spectra for the $^{24}Mg(^{12}C,2^{12}C)^{12}C$ reaction at angle pairs $\theta_1 = \theta_2$= 40.5^o and $\theta_1 = \theta_2$= 36.7^o are shown in Figs. (1)-(2). At the other two angle pairs, $\theta_1 = \theta_2$ 33.9^o and θ_1

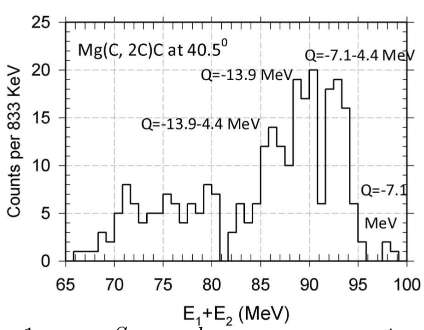

FIG. 1: *Summed energy spectrum for* $^{24}Mg(^{12}C,2^{12}C)^{12}C$ *at* 40.5^o.

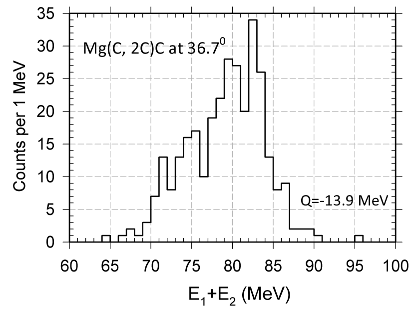

FIG. 2: *Same as Fig.1 except at* 36.7^o

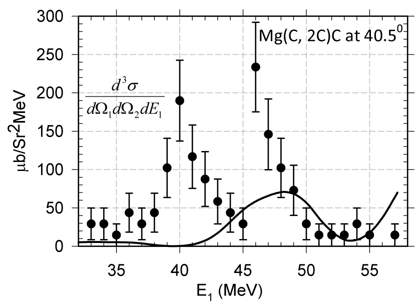

FIG. 3: *Energy sharing distribution for* $^{24}Mg(^{12}C,2^{12}C)^{12}C$ *at* 40.5^o*.Solid Line ZR-DWIA*31.25.*

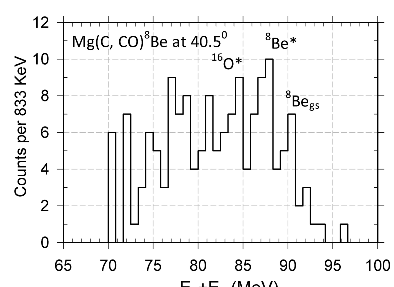

FIG. 4: *Summed energy spectrum for* $^{24}Mg(^{12}C,CO)^{8}Be$ *at* 40.5^o.

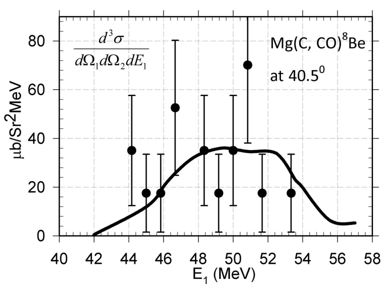

FIG. 5: *Energy sharing distribution for* $^{24}Mg(^{12}C,CO)^8Be$ *at* 40.5^o *Solid Line is FR-DWIA *15.13.*

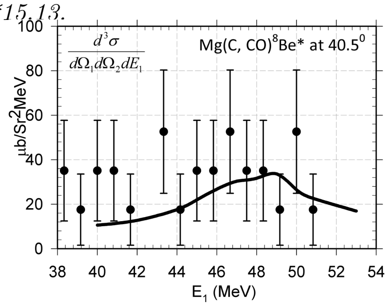

FIG. 6: *Energy sharing distribution for* $^{24}Mg(^{12}C,CO)^8Be^*$ *at* 40.5^o *Solid Line is FR-DWIA *31.25.*

$= \theta_2$ 49.6^o there are hardly any counts for the Q=-13.9 MeV.

It is noticed that except for the $\theta_1 = \theta_2 = 40.5^o$ summed energy spectrum, corresponding to the least recoil momentum q_R, the spectra at all the other three angles do not have significant counts at $E_1 + E_2 = 90MeV$, corresponding to the Q-value of $-13.9MeV$, for the knockout of $^{12}C_{(g.s.)}$ from the $^{24}Mg_{(g.s.)}$. From this $E_1 + E_2 = 90$ MeV data the energy sharing distribution is generated in Fig.3, this distribution has two peaks one at 41 MeV and the other at 46.5 MeV. However for $E_1 = E_2 = 45.0$ MeV corresponding to $q_R = 0$ one expects a peak (corresponding to knockout from $\ell = 0$ bound state of two $^{12}C_{(g.s.)}$ in the $^{24}Mg_{(g.s.)}$) corresponding to the cross section value of $29.2{\pm}20.6\mu b/sr^2MeV$. From kinematic considerations the E_1=44 and 45 MeV data does not have any resonance contributions and this low cross section calue compared to the even lower ZR-DWIA estimate of 1.6 $\mu b/sr^2MeV$ is too large and indicates the failure of the ZR-DWIA. Using all-through attractive $^{12}C +^{12} C$ t-matrix effective interaction a value of $\sim 7\mu b/sr^2MeV$ in the FR-DWIA is a signature of the failure of the all-through attractive $^{12}C +^{12} C$ interaction. Again necessitating the presence a repulsive core in the ^{12}C-^{12}C interaction as has been seen in the case of the 120 MeV $^{16}O(^{12}C,2^{12}C)^4He$ reaction[3, 4]. The two peaks on either side of the $E_1 = E_2 = 45.0$ MeV dip are estimated to arise as a result of final state interaction where the 14^+ -$^{24}Mg^*$ resonance, at 39 MeV excitation energy, decays into two $^{12}C_{(g.s.)}$'s observed as peaks at 41 MeV and 46.5 MeV on either side of the 45.0 MeV dip.

The summed energy spectrum for the 104 MeV $^{24}Mg(^{12}C,^{12}C^{16}O)^8Be$ reaction in the same experimental setup as above at $\theta_1 = \theta_2 = 40.5^o$ is shown in Fig.4. Clear peaks leading to the residual ^8Be and $^8Be^*_{3MeV2+state}$ are identified here. A fairly large number of counts are seen to account for this reaction. The minimum recoil momentum (q_R = ^{8}Be) = 97.5 MeV/c is large for this kinematics. A look at the energy sharing distribution in Fig.5 for $^{24}Mg(^{12}C,^{12}C^{16}O)^8Be$ reaction reveals a rise in cross section at 50.5 MeV due to the ^{24}Mg resonance, at 31.6 MeV excitation energy, decaying into ^{16}O and ^8Be. Significant cross section of $40{\pm}25\mu b/sr^2MeV$ at all the other energies correspond to the true knockout of ^{16}O from ^{24}Mg. An all through attractive $^{12}C +^{16} O$ interaction leads to an estimate of the FR-DWIA cross section with a spectroscopic factor of $\sim$ 15. Indicating a fairly large component of ^{16}O plus ^8Be component[2] in the $^{24}Mg_{(g.s.)}$ as also a repulsive core in the $^{12}C +^{16} O$ interaction. Results for the $^{24}Mg(^{12}C,^{12}C^{16}O)^8Be_{3MeV2+state}$ reaction shown in Fig.6 indicate no resonances and a spectroscopic factor of $\sim$ 31 and again a repulsive core in the ^{12}C+^{16}O interaction.The surprise part of this study is the discovery of a large component of $^8Be^*_{(3MeV2+state)}$ in the $^{24}Mg_{(g.s.)}$.

References

[1] M. Freer *et al*. Phys. Rev. C. **63**, 034317 (2001).

[2] A. A. Pilt and C. Wheatley. Phys. Lett. B. **76**, 11 (1978).

[3] B. N. Joshi *et al*. Phys. Rev. Lett. **106**, 022501 (2011).

[4] Arun. K. Jain and B. N. Joshi *et al*. Phys. Rev. Lett. **103**, 132503 (2009).