Compound nuclear origin of broad structures in proton spectra from low energy ^{12}C and ^{16}O induced reactions

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Introduction

In our earlier work [1–3] we had observed broad structures in γ-ray multiplicity gated proton spectra in low energy ^{12}C and ^{16}O induced reactions. These could not be understood within the statistical model (SM) of compound nuclear (CN) decay. An enhancement of nuclear level density (NLD), depending on the excitation energy (E_X) and angular momentum ($J\hbar$), could explain the structures in all the proton spectra. Another possible explanation of these structures could be a massive cluster transfer, populating doorway states in the final residue and producing high energy protons. However measurements in two entrance channels [3] suggested a compound nuclear origin for these structures.

In this work we investigate whether the proton spectra in the region of the broad structures are symmetric around 90° in the centre of mass (CM) system. An affirmative answer would strongly support the CN hypothesis. These measurements were made in the ^{12}C+^{93}Nb reaction at E(^{12}C)=40 MeV. Measurements were also made to address the entrance channel dependence at a lower excitation energy of the CN (E_X^{CN}) where the structures were more prominent than in Ref.[3]. For this the proton spectra were measured in the ^{16}O+^{89}Y reaction at E(^{16}O)=51 MeV and compared with our earlier measurements in the ^{12}C+^{93}Nb reaction at E(^{12}C)=42.5 MeV. Both these reactions should lead to the same CN ^{105}Ag at E_X^{CN} ~37.5 MeV.

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Experimental Details

The measurements were performed at the 14UD BARC-TIFR Pelletron accelerator in Mumbai using ^{12}C and ^{16}O beams. Self supporting rolled ^{93}Nb and ^{89}Y targets($\sim$ 99.9% purity) of thickness $\sim$ 0.5 mg/cm^2 were used. Additional targets of ^{12}C ($\sim$ 50 μg/cm^2) and Ta_2O_5 ($\sim$ 1 mg/cm^2 backed by $\sim$ 2 mg/cm^2 Ta) were used to assess and subtract the contributions due to C and O impurities present in the main targets. Protons were detected in NaI(Tl) scintillation detectors (4.4 cm $\phi \times$ 3.8 cm thick) placed at a distance of $\sim$ 14 cm from the target. For the measurements in the ^{12}C+^{93}Nb system, two detectors were placed at 52.5° and 122.5°. These correspond to CM angles of $\sim$ 55° and 125°, which are symmetric with respect to θ_{CM}=90°, for protons with energies in the region of the broad structures. In the ^{16}O+^{89}Y reaction, protons were detected at 122.5° and 153° with respect to the beam direction. A Si $\triangle$E - E telescope was placed at 10° to quantify the background due to C and O impurities in the main targets. All the NaI(Tl) detectors had an 8 μm thick havar entrance window and were covered in front with a tantalum foil of thickness $\sim$ 47 mg/cm^2 in order to stop the beam like particles. The standard pulse shape discrimination technique was employed to separate protons from γ-rays and alpha particles in the NaI(Tl) detectors. The energy calibration was done by measuring the elastically scattered protons of energies ranging from 10 to 24 MeV from ^{209}Bi and C targets. A 14-BGO multiplicity setup [1] was used to measure the low energy γ-rays in coincidence with the particle detectors. The

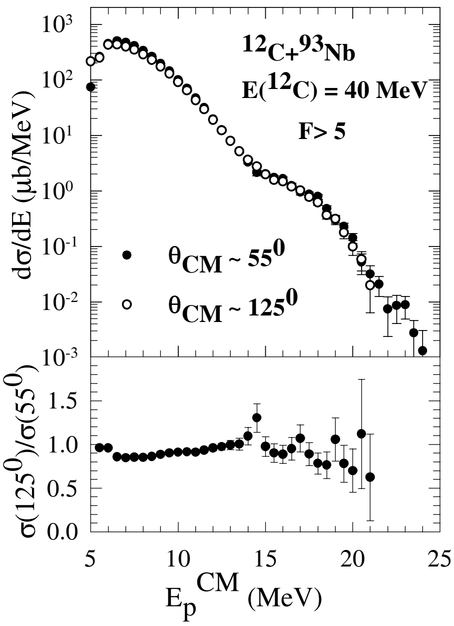

FIG. 1: Proton spectra from ^{12}C+^{93}Nb reaction for F>5 at angles symmetric to $\theta_{CM} \sim 90°$. The lower panel shows the ratio of the cross sections.

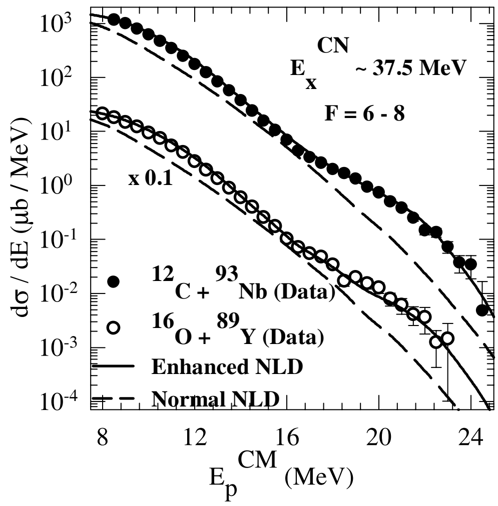

FIG. 2: Proton spectra along with SM calculations for F=6−8 from ^{16}O+^{89}Y and ^{12}C+^{93}Nb reactions.

total efficiency of the multiplicity setup was measured to be $\sim$ 55% for 662 keV γ-rays using a calibrated ^{137}Cs source.

Results and Discussion

Fig. 1 displays the proton spectra from ^{12}C+^{93}Nb reaction at E(^{12}C)=40 MeV for fold (F)>5 at the forward and backward angles in the CM system. Fold is defined as the number of BGO detectors firing simultaneously for any event in the particle detectors. This is related to the multiplicity and hence to the J populated in the final residue. While these spectra indicate symmetry about θ_{CM}=90°, a more sensitive visualisation is through a ratio plot shown in the lower panel. This ratio is fairly constant, within ±15%, over the energies measured. This indicates a forward-backward symmetry in accordance with the expectation from a CN origin of the broad structures.

Fig. 2 shows the fold gated proton spectra from the ^{16}O+^{89}Y and the earlier measured ^{12}C+^{93}Nb reaction for F window 6−8. The structures seen in the spectra from both the reactions are similar in shape. The SM calculations incorporating various prescriptions of NLD [1, 3] are also shown in the same figure. The observed structures do not corroborate with SM calculations using the conventional NLD. However, calculations with an enhanced NLD describe data from both the channels with similar (within 15%) enhancement parameters.

In conclusion, the broad structures in the γ-ray multiplicity gated proton spectra have a compound nuclear origin which implies an (E_X, J) dependent enhancement in nuclear level density. It will be interesting to see if this is a generic feature or special to a particular mass region.

References

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