Dominant emission of non-statistical alpha particles in ^{11}B and ^{12}C induced fusion reactions near Coulomb barrier energies

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Introduction

In our earlier work[1], measurements of alpha particle spectra in ^{12}C and ^{16}O induced reaction on ^{93}Nb were reported. In the recent work[2], α-particle spectra were also measured in $^{13}C + ^{93}Nb$ and $^{12}C + ^{58}Ni$ reactions. All these measurements were made at beam energies around the Coulomb barrier in the entrance channels. An unusual feature was observed for $^{12,13}C$ projectile at near barrier energies. The measured spectra showed the maximum yield at an alpha energy below the evaporation peak predicted by the Statistical Model(SM). This discrepancy was absent at energies well above the barrier. Surprisingly, no such discrepancy was observed in the case of ^{16}O induced reaction.

This discrepancy could imply that the α-particle emission take place from a deformed configuration at near barrier energies. The deformation increases transmission probability of lower energy α-particles. Hence emission from a deformed system prior to full equilibration can lead to lower energies of alpha particles than that predicted by SM. On the other hand it could be due to an unusually large contribution from non compound processes such as massive cluster transfer or projectile breakup. The main motivations of the present work are to get more insight into this discrepancy by using other than Carbon projectile and to infer reaction mechanism from a measurements of the alpha spectra at forward and backward angles which are symmetric around 90° in the centre of mass (CM) system. The forward-backward symmetry of spectra would strongly support the compound nuclear(CN) reaction mechanism while asymmetry would imply non-compound reaction mechanism. The forward angle inclusive alpha spectra are dominated by Carbon and Oxygen impurities in the target material. The compound nuclear reactions with these light impurities are populated with low angular momentum in comparison to the reaction of interest. Hence α-spectra were measured in coincidence with a low energy gamma multiplicity in order to minimize the effect of Carbon and Oxygen impurities. In this experiment the fold gated α-particle spectra were measured in the reactions $^{12}C + ^{93}Nb$ and $^{11}B + ^{93}Nb$ at ^{12}C beam energy of 40 MeV and at ^{11}B beam energies of 32.5 and 40 MeV.

Experimental Details

The experiment was performed at the 14UD BARC-TIFR Pelletron at Mumbai using ^{12}C and ^{11}B beams. The target was a self supporting ^{93}Nb foil of thickness 0.5 mg/cm^2. The α-particles were detected using three silicon surface barrier ΔE-E telescopes with thickness combinations of (25μm + 2mm), (25μm + 2mm) and (30μm + 2mm). The first two telescopes were kept at forward angles of 50°. The third telescope was placed at backward angle of 125° with respect to the beam direction. All these telescopes were placed at a distance of 7 cm from the target. A Si-telescope (50μm + 2mm) was also placed at an angle of 10° and at a distance of 5.5 cm from the target to estimate background due to Carbon and Oxygen impurities in the main target. For this purpose, alpha spectra were measured using a Carbon and Oxygen (WO_3) target at each of the corresponding beam energies. These spectra were normalized and subtracted from the main spectra. The alpha spectra were also measured in coincidence with the low energy gamma-rays emitted from the residual nuclei populated below the particle emission threshold. The multiplicities of these gamma-rays are related to the angular momentum populated in the compound systems. A 38-BGO detector multiplicity array was used for gamma ray multiplicity measurements. The number of BGO detectors fired in coincidence with the charged particle detectors, henceforth called fold (F), was recorded in an event by event mode in a VME data acquisition system. The telescopes were calibrated using the standard radioactive α-sources.

Results and Discussion

The experimental data were analyzed to generate 2-dimentional fold (F) versus alpha energy spectra. The laboratory energy spectra were derived from projected spectra after taking into account the energy loss in the ΔE detector. The measured inclusive α-spectra for $^{11}B + ^{93}Nb$ reaction in the CM at E_{lab} = 32.5 and 40 MeV are shown in Fig.1(a) along with SM model predictions by CASCADE(CAS)[3] for fusion cross section taken from CCFUS[4]. It is clear from the Fig.1 (a) that for this reaction also the behavior is qualitatively similar to $^{12}C + ^{93}Nb$ reaction, showing a discrepancy in alpha spectrum at near barrier energy and reasonable agreement for above barrier energy.

The fold gated alpha spectra at forward and backward angles were measured to ascertain reaction mechanism responsible for the above discrepancy. The Fig.1(b) shows experimental fold gated alpha spectra for fold(F) > 5 at lab angles of 55° and 120° corresponding to centre of mass(CM) angles of 55° and 125° which are symmetric angles in CM for this reaction. These spectra show large yield at backward angle (Fig. 1(b)) in comparison to that of forward angle and shift of ~1.5 MeV in the peak positions. This indicates that the spectra are not symmetric in the CM. The spectra were also compared with a simulated Monte Carlo CASCADE (SMCC)[1] statistical model calculations. The solid line in the figure shows SMCC calculations for F>5. A comparison with the experimental spectra shows that the SMCC calculations reasonably reproduce the overall shape of the spectra at forward angle of 50° but fails to reproduce back angle data. This implies that the backward angle α-spectra are mostly dominated by non-compound nuclear reactions. Qualitatively similar results were obtained for $^{11}B + ^{93}Nb$ reaction at near barrier energy as shown in Fig.1(c).

In summary, the near Coulomb barrier discrepancy of alpha spectrum is not specific to $^{12,13}C$ isotopes and the compound nuclear reaction mechanism is not responsible for evaporation peak discrepancy. It is quite possible that other reaction mechanism like massive cluster transfer or projectile breakup may be responsible for the observed features in the alpha spectra for ^{12}C and ^{11}B induced reactions at Coulomb barrier energies. Complete angular distribution measurements and calculations are required to ascertain the reaction mechanism.

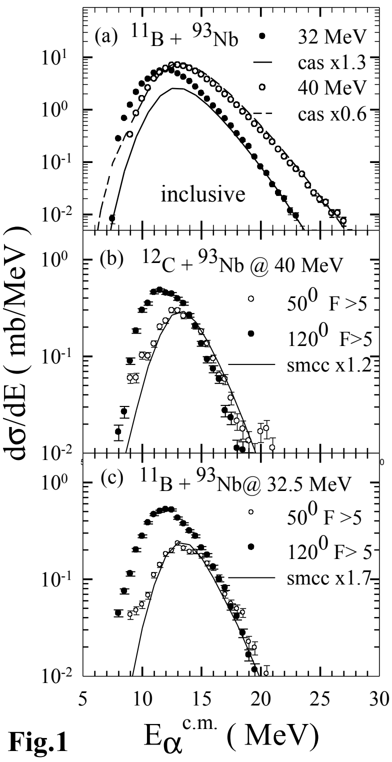

Fig.1

References

[1] E. T. Mirgule *et al.*, Phys. Rev. C82, 064608 (2010).

[2] G. Mishra *et al.*, DAE Symp. On Nucl.Phys. **56**, 454 (2011).

[3] F. Puhlhofer, Nucl. Phys. A280, 267(1980).

[4] C. S. Dasso *et al.*, Com. Phy. Com.46, 187(1987).