Alpha particle spectra in ^{12,13}C-induced reactions - dominantly non-statistical at near-barrier energies?

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Introduction

In a recent work [1], we reported measurements of alpha particle spectra in ^{12}C and ^{16}O induced reaction on ^{93}Nb target at beam energies around the Coulomb barrier in the entrance channel. An intriguing feature was observed for the ^{12}C projectile at near-barrier energies. The experimental spectra showed maximum yield at an alpha energy lower than that of the evaporation bump predicted by the statistical model. The discrepancy was not present at energies well above the barrier. Interestingly, no discrepancy was seen for the ^{16}O projectile even at the near-barrier energy. These observations point towards a special role played by ^{12}C in near-barrier heavy ion reactions. This is possibly related to the highly deformed alpha-cluster configuration in ^{12}C excited on the way to fusion. The emission from a deformed system prior to full equilibration can result in lower energies of the alpha particles than that predicted by the statistical model. A conventional compound nuclear statistical model thus fails for this projectile at near-barrier energies.

As a check for the special role played by ^{12}C, it is interesting to investigate the phenomenon with projectiles close to ^{12}C. In the present paper, we report measurements made with ^{13}C projectile on Nb target at beam energies near and above the Coulomb barrier energies. Measurements were also made with ^{12}C bombarding ^{58}Ni in order to check the target dependence of the observed discrepancy.

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Experimental Details

The reactions studied were ^{13}C+^{93}Nb at beam energies of 40 and 50 MeV and ^{12}C+^{58}Ni at 32 and 40 MeV. The lower beam energies correspond to the Coulomb barrier in the respective entrance channels. Measurements were also made in the reaction ^{12}C+^{93}Nb at 40 MeV to cross check our earlier observation. The experiments were performed with the ion beams from the Mumbai Pelletron accelerator. The natural Nb and 99.9% enriched ^{58}Ni targets were self-supporting and rolled to $\sim$0.5 mg/cm^2 thickness. Alpha particles were measured, in a 1.5 metre diameter scattering chamber, with two silicon surface barrier telescopes consisting of ΔE and E detectors. The thickness combinations were 26μ - 1mm and 14μ - 2mm for the detectors placed at 125° and 150°, respectively, with respect to the beam direction. The energy calibration of the detectors was done with characteristic alpha groups from the ^{12}C+^{12}C reaction, leading to the ground and low-lying excited states of ^{20}Ne. For subtracting the background from the carbon and oxygen impurities in the main target, measurements were also made with C and WO_3 targets and the spectra were subtracted after proper normalisation. The final spectra in the laboratory system were converted to the centre of mass (c.m.) system.

Results and Discussion

The average c.m. cross sections, as a function of alpha energy $E_\alpha^{c.m.}$, were derived from the measurements with both the detectors. The resulting c.m. spectra are shown in Fig. 1 for the various cases. Table 1 gives the experimental energy values for the maximum cross sections (E_{max}) and the evaporation bump en-

TABLE I: E_{max} and E_{ev} (see text for definition) for various cases.

System	E_{lab} (MeV)	E_{max} (MeV)	E_{ev} (MeV)
$^{12}C+^{58}Ni$	32.0	9.08±0.4	10.3±0.2
	40.0	10.5±0.2	10.8±0.2
$^{12}C+^{93}Nb$	40.0	11.2±0.2	13.4±0.2
$^{13}C+^{93}Nb$	40.0	12.3±0.2	13.4±0.2
	50.0	13.5±0.2	13.7±0.2

ergies (E_{ev}) predicted by the statistical model (SM). The uncertainties in E_{ev} arise from the different choices of the input alpha optical potential, nuclear level density etc. in the SM calculations. For the 40 MeV ^{12}C induced reaction on Nb, the discrepancy seen in the present work agrees with earlier observations. For the $^{12}C+^{58}Ni$ reaction, the behaviour is qualitatively similar showing a discrepancy at the near-barrier energy and a reasonable agreement at the above-barrier energies. Quantitatively, the measure of the discrepancy (difference between E_{max} and E_{ev}) seems to depend on the target. For the ^{13}C induced reaction on Nb, again a similar near-barrier discrepancy is observed, although, of a lesser magnitude compared to the ^{12}C case.

The observations from the present and the earlier experiments suggest that the near-barrier discrepancy in the alpha spectrum is neither very projectile-specific nor very generic. The reasons for the observed discrepancy in the ^{12}C induced reaction gets diluted, but still persist, when one neutron is added to the projectile.

The observed near-barrier spectra could also arise from the non-statistical massive transfer reactions leading to alpha particles in the exit channel. However, it would mean that compound nuclear contribution is very small, otherwise the spectrum would have two broad bumps corresponding to the two processes. Again, the alpha clustering in the projectile could play a role although the observed

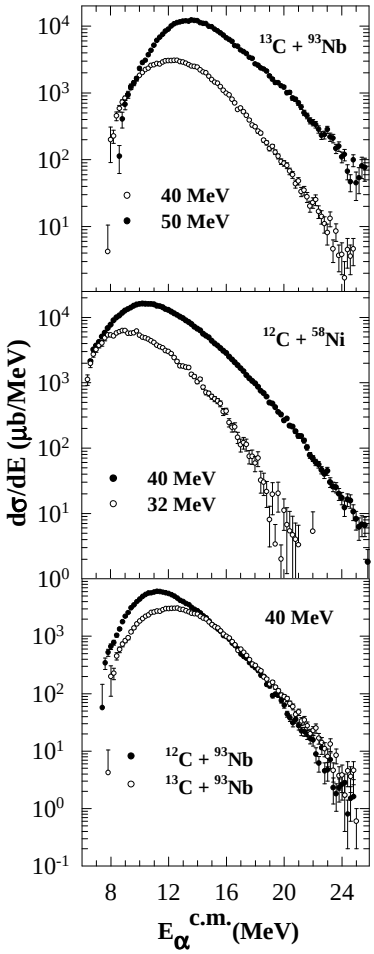

FIG. 1: Alpha particle spectra in the c.m. system for the various cases.

dominance of the non-statistical process in the reactions induced by C-isotopes, but not with ^{16}O, is intriguing. More exclusive measurements with various projectile-target combinations covering a wide angular range as well as theoretical calculations for the two processes are necessary for understanding these interesting observations.

References

[1] E. T. Mirgule et al. Phys. Rev. C**82**, 064608 (2010).