# Deformation in $^{28}Si^{*}$ produced via $^{16}O+^{12}C$ reaction

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## Introduction

Several investigations have been made recently to study the reactions involving $\alpha$-cluster nuclei (e.g., $^{20}Ne + ^{12}C$, $^{24}Mg + ^{12}C$, $^{28}Si + ^{12}C$, etc.). In all these cases, a long-lived highly deformed di-nucleus was formed [1]. So, light charged particle (LCP) spectroscopy can also be used as a probe to study such types of deformed systems. Recently, it was reported that, for $\alpha$-cluster system $^{16}O + ^{12}C$ [2], there is an enhancement in the boron yield for the beam energy 7-10 MeV/nucleon which indicates the survival of long-lived deformed di-nuclear orbiting at this range of energy. This has encouraged us to explore the quantitative deformation of the $^{16}O + ^{12}C$ di-nuclear system at same energy range.

## Experimental details

The experiment was performed at VECC, Kolkata, using $^{16}O$ ion beams at energies of 117, 125, 145 and 160 MeV respectively. The target used was 514 $\mu$g/cm$^2$ self-supporting $^{12}C$. The $\alpha$ particles were detected using Si(SB) telescope ($\sim$ 10$\mu$m $\Delta$E, $\sim$ 5mm E). Inclusive energy distributions for the light charged particles have been measured at different lab angles. Centre of mass (c.m.) energy spectra of α particles at different beam energies are shown in Fig. 1 by solid points.

## Results and discussion

Centre of mass (c.m.) angular distribution of $\alpha$ particles have been shown in Fig 2. for all the energies where it is seen that the values of d$\sigma$/dθ is constant over the whole range of observed c.m. angles at all beam energies. So, $d\sigma/d\Omega \propto 1/\sin\theta_{c.m.}$, which is the characteristic of emission from a equilibrated compound nucleus (CN). Average velocities of $\alpha$ particles emitted at different beam energies are plotted in Fig. 3 as function of $v_{\parallel}$ vs. $v_{\perp}$. The average velocity falls on a circle with centre at CN velocity, which implies that average velocities or the energies of the $\alpha$ particles are independent of centre of mass emission angles. It again indicates that the $\alpha$ particles are emitted from a fully energy equilibrated source moving with velocities, $v_{CN}$ indicated by arrows.

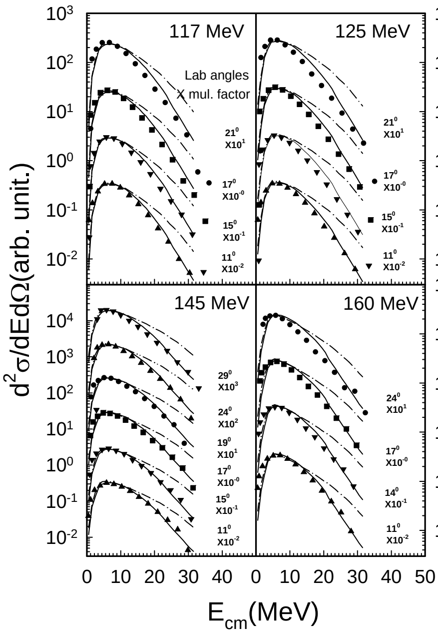


FIG. 1: Energy spectra (c.m.) of $\alpha$ particles obtained at different lab angles.

Energy spectra (c.m) were compared with CASCADE [3] calculations and are shown in Fig.1 by dash-dot-dash & solid lines. For these calculations, critical angular momenta were taken as 20, 21, 22 and 23$\hbar$ for 117, 125, 145 and 160 MeV respectively [2]. All the other parameters were taken from [3,4] with RFACT=1. The dash-dot-dash lines represent the results from CASCADE calculation with default radius parameter $r_0$= 1.29, $\delta_1$ and $\delta_2$=0. It is clear that slope of the calculated spectrum is higher than that of the experimental one. There are two important parameters in CASCADE which mainly control the emission of evaporation spectra, the spin dependent level density which defines the available phase space and the transmission coefficients that control access to this space. The level density ρ(E,J) is given by well known Fermi gas expression:

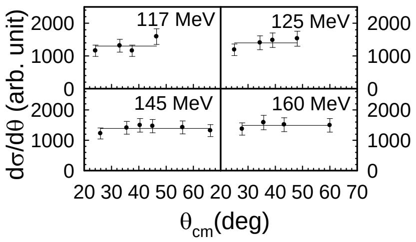


FIG. 2: Angular distribution of $\alpha$ particles as a function of c.m. angles, $\theta_{cm}$.

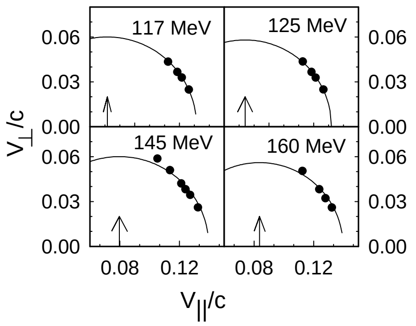


FIG. 3: Average velocity curve.

$$\rho = \frac{(2J+1)}{12} a^{1/2} \left(\frac{\hbar^2}{2I_{eff}}\right)^{3/2} \frac{1}{\left(E+T-\Delta-E_J\right)^2}$$

$$\times \exp\left[2\left\{a\left(E-\Delta-E_J\right)\right\}^{\frac{1}{2}}\right]$$

where a is the level density parameter taken as a=A/8, E is the total excitation energy, J is angular momentum, T is the thermodynamic temperature, Δ is the pairing correction, $E_J = \frac{\hbar^2}{2I_{eff}} J(J+1)$ is the rotational energy for effective moment of inertia $I_{eff} = I_0(1 + \delta_1 J^2 + \delta_1 J^4)$, rigid body moment of inertia $I_0 = (2/5)A^{5/3} r_0^2$, $\delta_1$ and $\delta_2$ are deformation parameters. So, from all the above equations, it is clear that by changing $r_0$, $\delta_1$ and $\delta_2$, it may be possible to reproduce the experimental spectra. By increasing $r_0$, both the transmission coefficient and level density will be affected. It reduces the potential barrier which increases the transmission coefficient. Simultaneously, increases in $r_0$, increases the $I_{eff}$ which increases the available phase space. But from the Fig. 1., it is seen that low energy part of the experimental $\alpha$ particle spectra matches with the theoretical spectra. So we varied only $\delta_1$ and $\delta_2$ to reproduce the higher part of the spectra with CASCADE as shown by the solid lines. The optimized values of deformation parameter at each incident energy are given in Table I. From the table it is clear that the effective value of radius parameter $r_{eff}$ is increased with increases in energy where $r_{eff}$ is calculated by using equation, $r_{eff}^2 = r_0^2 \frac{\sum_0^{J_{cr}}(1+\delta_1 J^2+\delta_2 J^4)(2J+1)}{\sum_0^{J_{cr}}(2J+1)}$.

TABLE I: The optimized values of deformation parameters.

| $E_{lab}$ MeV | E MeV | $J_{cr}$ ħ | $r_0$ fm | $\delta_1$ $\times 10^{-3}$ | $\delta_2$ $\times 10^{-8}$ | $r_{eff}$ fm |
|---|---|---|---|---|---|---|
| 117 | 67 | 20 | 1.29 | 1.9 | 2.0 | 1.52 |
| 125 | 70 | 21 | 1.29 | 2.1 | 2.0 | 1.57 |
| 145 | 79 | 22 | 1.29 | 2.3 | 2.0 | 1.62 |
| 160 | 85 | 23 | 1.29 | 2.5 | 2.0 | 1.67 |

## Summary

It has been found that the $\alpha$ particles are emitted from fully equilibrated compound nucleus at all beam energies. But the experimental $\alpha$ particle energy spectra cannot explain by CASCADE with zero deformation parameter. To explain it, deformation parameter has to be increased. Non-zero value of the deformation parameters are another indication of long-lived deformed di-nuclear orbiting in $^{16}O$+$^{12}C$ reaction as indicated in [2].

## References

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