Determination of hexadecapole deformation for ^{160}Gd nucleus using quasi-elastic scattering

Sukanya De,[1] G. Mohanto,[1] A. Parihari,[1,2] E.T. Mirgule,[1] B. Srinivasan,[1] P.C. Rout,[1] M. Kushwaha,[1,2] S. Arora,[3] C. Joshi,[4] A. Sharma,[5] B.K. Nayak[1] and A. Saxena[1]

[1]*Bhabha Atomic Research Centre, Trombay, Mumbai, India*
[2]*Department of Physics, University of Mumbai, Mumbai, India*
[3]*School of Physics and Materials Science, Thapar University, Punjab, India*
[4]*The Maharaja Sayajirao University of Baroda, Gujarat, India*
[5]*IET, Bhaddal, Chandigarh, Punjab, India*

Introduction

Nuclear structure plays an important role in heavy-ion fusion reactions at around Coulomb barrier energies by enhancing the fusion cross-section .When coupling of internal degrees of freedom take place with the relative motion of the reaction participants, a distribution of fusion barrier is observed instead of a single barrier [1]. Effects of channel coupling can be better visualised when the double derivative of the product of energy and fusion cross-section represents the fusion barrier distribution. Proper knowledge of quadrupole deformation parameter (β_2) and hexadecapole deformation parameter (β_4) can well account for the collective excitations due to rotation. Accurate values of β_2 have been obtained using electromagnetic probes [2], but experimental determination of β_4 is difficult with the results having large uncertainty and model-dependency. Various techniques like coulomb excitation, inelastic proton scattering have been used to obtain the value of β_4. In recent time, attempts have been made to obtain β_4 value using fusion. In the present experiment, we have obtained the value of β_4 for ^{160}Gd using quasi-elastic (QEL) scattering at backward angles which is a process complementary to fusion.

Experimental set-up

The experiment was performed at TIFR-BARC pelletron facility, Mumbai with ^{16}O beam having laboratory energy (E_{lab}) ranging from 57 to 79 MeV in steps of 2 MeV. An isotopically enriched (98.2%) 50 μg/cm^2 thick target of ^{160}Gd having a carbon backing of thickness 20 μg/cm^2 was used for the experiment. Two Silicon Surface Barrier Detectors (SSBDs) were placed at $\pm 10^0$ with respect to the beam direction to monitor the beam. In order to detect the projectile-like fragments, four ΔE-E telescopes consisting of SSBDs were placed at angles of $\pm 170^o$ (T2,T3) and $\pm 150^o$ (T1,T4) with respect to the beam direction at distances of 16.1 cm and 13.5 cm from the target position respectively. The thicknesses of the detectors were as follows: ΔE1, ΔE4=25 μm, ΔE2,ΔE3=20μm, E1,E3=2 mm, E2, E4=1 mm..

Analysis of experimental data

The quasi-elastic yields in the ΔE-E detectors at same angles on either side of the beam direction are summed up. The ratio ($d\sigma_{qel}/d\Omega$) at $\pm 170^o$ and $\pm 150^o$ was obtained by dividing the yields in the the corresponding telescope detectors by the sum of the yields in the two monitor detectors. The ratios ($d\sigma_{qel}/d\sigma_R$) at $\pm 170^o$ and $\pm 150^o$ were obtained by taking ratio of ($d\sigma_{qel}/d\Omega$) to Rutherford cross-section at corresponding angles. As the detector can't be placed at $\theta = 180^o$ in order to obtain the barrier distribution for $\ell=0$, a centrifugal correction has been carried out for the center-of-mass energy (E_{cm}). Barrier distribution $D_{qel}(E)$ at effective energy (E_{eff}) was obtained as follows:

$$D_{qel}(E) = -\frac{d}{dE_{eff}}\left(\frac{d\sigma_{qel}}{d\sigma_R}\right)$$

Fig.1. shows the ratio of quasi-elastic to the Rutherford cross-section at different energies. The barrier distribution thereby extracted is shown in Fig.2. The magenta dots and the blue dots in the following figures show values obtained from the detectors placed at $\pm 170^o$ and $\pm 150^o$, respectively. It is observed from Figs. 1 and 2 that the quasi-elastic excitation function and the extracted $D_{qel}(E)$ for the ΔE-E detectors placed at two different backward

angles are quite consistent with each other.

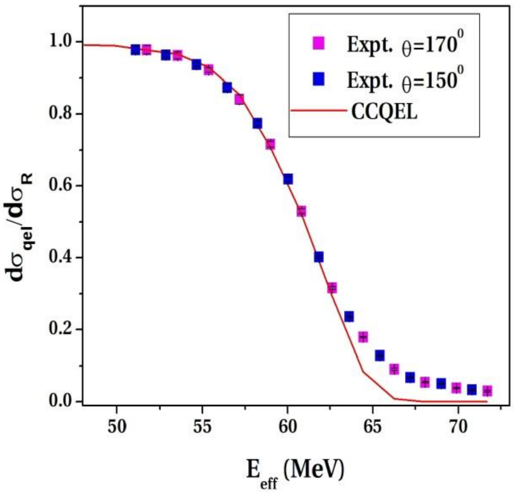

Fig.1. Comparison of experimental quasi-elastic scattering excitation function with the prediction of CCQEL.

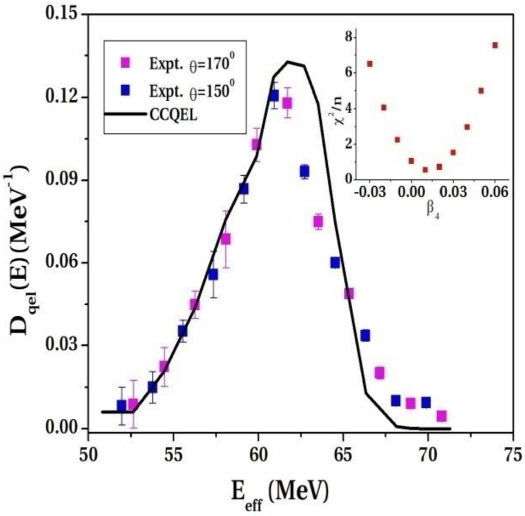

Fig.2. The barrier distribution $D_{qel}(E)$ obtained for $^{16}O+^{160}Gd$ system compared with the prediction of CCQEL code for $\beta_4=0.013$ corresponding to the minimum value of $\chi2$ as shown in inset.

A modified version of the code CCFULL (CCQEL) [3] was used to fit the experimental data by carrying out coupled-channel calculations. A Woods-Saxon potential with geometrical parameters $r_o=1.08$ fm and $a_o=0.8$ fm was used. Rotational coupling has been included for ^{160}Gd keeping the deformation parameter $\beta_2=0.353$. The experimental data could be fitted even better with the inclusion of β_4. $\chi2$ minimisation technique was used to obtain the best fit value of β_4. The variation of $\chi2$ per degree of freedom(n) with β_4 is parabolic in nature as shown in the inset in Fig.2, having a minimum value for $\beta_4=0.013$. Table 1 gives a comparison of the value of β_4 for ^{160}Gd obtained in the present experiment with literature values obtained from different experimental techniques and theoretical predictions. The minimum value of $\chi2/n$ being less than 1, the error was obtained to be ±0.07 by taking the limiting value $(\chi2)_{lim}=(\chi2)_{min}+1$ [4].

Measurement techniques/ Theoretical predictions	Value of β_4 for ^{160}Gd
Present work	0.013±0.007
Finite-range droplet macroscopic model [5]	0.065
Inelastic proton scattering [6]	0.0471(25)
Coulomb excitation [7]	0.032±0.024
LISA quantal calculations [8]	0.016±0.022

Table 1. Comparison of β_4 value for ^{160}Gd obtained in the present experiment with literature values obtained from different experimental techniques and theoretical predictions.

Acknowledgements

We thank the pelletron crew for smooth operation of beam during the experiment.

References

1. H. M. Jia, *et al.* Phys. Rev. C 90, 031601(R) (2014).
2. S. Raman *et al.* Atomic Data and Nuclear Data Tables 78 1–128 (2001).
3. K. Hagino *et al.* Computer Physics Communications 123 (1999) 143–152.
4. D. Cline *et al.* Nuclear Instruments and Methods 82 (I970) 29T-293.
5. P. Möller *et al.* Atomic data and nuclear data tables 59, 185-381 (1995).
6. T. Ichihara *et al.* Phys. Rev. C, Volume 36, Number 5 , November 1987.
7. K. A. Erb *et al.* Phys. Rev. Lett. 29, 1010 (1972).
8. A. H. Shaw *et al.* Phys. Rev. C 10, 263 (1974).