Determination of hexadecapole deformation of ^{176}Yb

G. Mohanto[1],* A. Parihari[1,2], A. Pal[1], A. Gandhi[3], S. De[1], E. T. Mirgule[1], K. Ramachandran[1], B. Srinivasan[1], K. Kalita[4], A. Kumar[3], K. Rani[5], A. Tejaswi[6], C. Vadagama[7], Vishal Bharud[8], Y. K. Gupta[1], L. S. Danu[1], B. J. Roy[1], M. Kushwaha[1], D. Sarkar[1,2], B. K. Nayak[1], and A. Saxena[1]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
[2]*Department of Physics, University of Mumbai,400098 INDIA.*
[3]*Department of Physics, Banaras Hindu University, Varanasi 221005 INDIA*
[4]*Department of Physics, Gauhati University, Guahati 781014 INDIA*
[5]*Department of Physics, Panjab University, Chandigarh 160014 INDIA*
[6]*Department of Nuclear Physics, Andhra University, Vishakhapatnam 530003 INDIA*
[7]*Department of Physics, Sir P. T. Sarvajanik College of Science, VNSGU, Surat 395001 INDIA and*
[8]*Department of Physics, Savitribai Phule Pune University, Pune 411007 INDIA*

Introduction

Precise determination of nuclear hexadecapole (β_4) deformation parameter is challenging. Unlike quadrupole deformation, hexadecapole deformation can not be measured easily by electromagnetic probes. Scattering measurements (α, e^- and proton), Coulomb excitation and fusion excitation function measurements have been extensively used to determine β_4 [1–5]. Experimental uncertainity in the value of β_4 is high in some of these methods. Other experimental techniques that have potential to be used for the determinion of the hexadecapole deformation parameter precisely are looked for. At the time of fusion reaction, the internal degrees of freedom of the reaction partners couple to the relative motion of fusion resulting in a distribution of barriers instead of a single uncoupled barrier. The distribution of the barrier height $D^{fus}(E)$ carries the information about the nature as well as strength of the coupling. Hence by measuring the barrier distribution one can obtain the value of the hexadecapole deformation parameter provided other coupling conditions are properly taken care. For most of the even-even nuclei, the quadrapole deformation is experimentally measured with good precision [6]. Hence hexadecapole deformation parameter for these nuclei can be determined by measuring the barrier distribution. For obtaining the barrier distribution quasi elastic scattering measurement is an alternative to fusion excitation measurement [7] and can be used to obtain the value of β_4 [8]. In the present study we have measured the quasi elastic excitation function for the reaction ^{16}O + ^{176}Yb to measure the β_4 value for ^{176}Yb.

Experiment

The experiment has been carried out at the BARC-TIFR 14UD Pelletron facility using ^{16}O beam on ^{176}Yb target. Enriched (96.63%) isotope of ^{176}Yb with thickness 170 μg/cm^2 was deposited on carbon backing of thickness 25 μg/cm^2. Beam energy was varied by a step of 2 MeV in the energy range 54 to 84 MeV. To detect beam like particles at back angles four $\Delta E - E$ telescope detectors, consisting of silicon surface barrier detectors (SSBDs), were placed at ±150° and ±170° with respect to the beam direction. Thicknesses of ΔE detectors were 15 μm and that of E detectors were 1500 μm. The detectors were placed at a distance of 27.7 cm from the target. Angular coverage of each telescope detector were ±0.5°. Two monitor detectors were used at an angle of ±20° for normalization purpose.

---

*Electronic address: `gayatrimohanto@gmail.com`

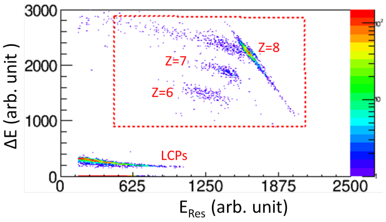

FIG. 1: Energy loss (ΔE) versus residual energy (E_{res}) at beam energy $E_{lab} = 70$ MeV.

Results and Discussion

A typical spectrum of energy loss (ΔE) versus residual energy (E_{res}) at 70 MeV beam energy is shown in Fig. 1. Quasi elastic yield was taken by considering elastic, inelastic and transfer events as shown in Fig. 1 by a rectangular cut. Quasi elastic differential cross sections were obtained by taking ratio of quasi elastic yield to the monitor detector yield. The ratio of quasi elastic differential cross section to the Rutherford differential cross section ($\frac{d\sigma_{qel}}{d\sigma_{Ruth}}$) was calculated as a function of energy which is shown in Fig.2(a). The centre of mass energy ($E_{c.m.}$) was corrected by incorporating the centrifugal correction to obtain the effective energy (E_{eff}). The quasi elastic barrier distribution (shown in Fig.2(b)) was obtained by taking first derivative of ($\frac{d\sigma_{qel}}{d\sigma_{Ruth}}$) with respect to the effective energy.

Coupled channel calculation was carried out using a modified version of CCFULL(CCQEL) [9] to reproduce the ($\frac{d\sigma_{qel}}{d\sigma_{Ruth}}$) values and corresponding barrier distribution. The value of β_4 was obtained using χ^2 minimizing technique. The value of β_4 was compared with the values measured by other experimental techniques as well as with the theoretical prediction. The β_4 value, determined in the present experiment, shows agreement with the theoretical prediction as well as with the earlier reported values measured by α, e^- scattering whereas, large deviation was observed when compared with the values measured by Coulomb excitation and fusion excitation.

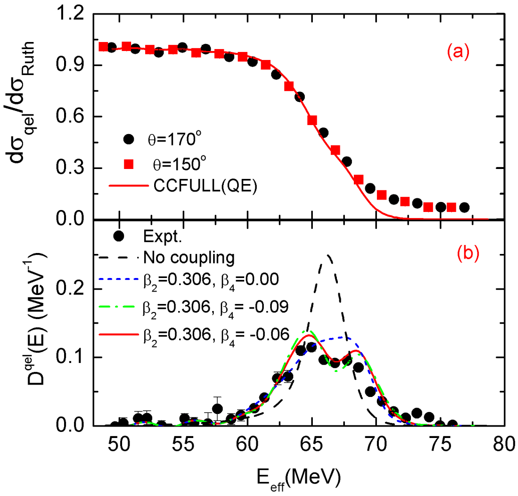

FIG. 2: (a)($\frac{d\sigma_{qel}}{d\sigma_{Ruth}}$)) as a function of energy for the reaction ^{16}O + ^{176}Yb at laboratory angles 170° (solid circles) and 150° (solid squares), respectively. (b)Experimentally obtained barrier distribution along with CCQEL prediction with different coupling conditions (circles). The black dashed line is calculated barrier distribution without any coupling. The blue short dashed, red solid and green dot-dashed lines are from coupled channel calculations with $\beta_2 = 0.305$ and $\beta_4 = 0.00, -0.06$ and -0.09, respectively.

Acknowledgments

We thank the Pelletron operating crew for providing good quality beam during the experiment. We thank Dr. K. Hagino for his valuable suggestions on quasi elastic coupled channel calculations.

References

[1] D. L. Hendrie *et al.* Phys. Letts. B. **26**, 127 (1968).
[2] T. Cooper *et al.*Phys. Rev. C. **13**, 1083 (1976).
[3] T. Ichihara *et al.* Phys. Rev. C. **36**, 1754 (1987).
[4] H. J. Wollersheim *et al.* Phys. Rev. C. **584**, 190 (1995).
[5] T. Rajbangshi *et al.* Phys. Rev. C. **93**, 054622 (2016).
[6] S. Raman *et al.* Atomic Data and Nuclear Data Tables **78**, 1128 (2001).
[7] H. Timmers *et al.* Nucl. Phys. A. **11**, 2008 (1975).
[8] H. M. Jia *et al.* Phys. Rev. C. **90**, 031601(R) (2014).
[9] K. Hagino *et al.* Comput. Phys. Comm. **123**, 143 (1999).