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Influence of Deformation/Orientation on Fusion Cross Section Induced By Heavy Ions

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***Abstract*— The fusion cross sections at sub-barrier energies depends on the couplings of various reaction channels such as deformation/orientation, non-elastic channels etc. The fusion cross sections may be either enhanced or hindered depending on their influences. Experiments are attempted to extract many parameters like hexadecapole deformations (β4) through fusion excitation function as well as by quasi-elastic measurements all over the world. The challenging experiments are performed on 16O + 176Yb, 174Yb at Inter University Accelerator Centre, New Delhi and at BARC-TIFR pelletron accelerator facilities and the results are compared. Experimental method that can give the β4 with less uncertainty is highly sought after between these two measurements. Recently, Quasi elastic scattering measurement around the barrier energies, at 150◦ and 170◦ with respect to beam direction, has been carried out to obtain the barrier distribution for the reaction 16O+ 176Yb. The measured barrier distribution has been compared with coupled channel calculation. The β4 value is obtained from the best fit of the experimental barrier distribution using minimisation χ 2 technique.**

I. INTRODUCTION

Fusion reactions are influenced by the internal structure like deformation/orientation of the interacting nuclei [1-3]. Experimental and theoretical evidences proved that fusion cross sections around the Coulomb barrier induced by heavy ions is strongly enhanced by the quadrupole and /or hexa-decapole deformations [2]. Various models emerged in this regime predict the couplings of non-elastic channel, transfer reaction etc. plays an important role in sub-barrier fusion enhancement. Therefore, till a definite conclusion is not found globally on sub-barrier fusion. The barrier distributions are known to be highly sensitive to higher order nuclear deformation. The internal degrees of freedom of the reaction partners couple to the relative motion of fusion results in a average barrier instead of a single uncoupled barrier. For estimating hexa-decapole deformation either fusion excitation technique or quasi-elastic measurement have become an important tool in the present days.

II. EXPERIMENTAL DETAILS

An attempt has been put to reply all insights by conducting experiments with pelletron accelerator facilities around the world and inside India. Most of the lanthanides group elements like Yb(174,176) shows both positive and negative hexa-decapole deformation prominently, so the fusion cross sections varies as shown in Fig.1. There are other systems like 186W, 154Sm, 180Hf, 62Ni etc. which shows similar behaviours. In this paper we represent an Experiment performed with 16O +174,176Yb by two techniques which are globally accepted. The first one via the measurement of fusion excitation function at sub-barrier energies using a recoil mass spectrometer in IUAC, New Delhi[2] and other one by measuring the back angled quasi-elastic scattering measurements using BARC-TIFR pelletron accelerator facility, Mumbai[4].

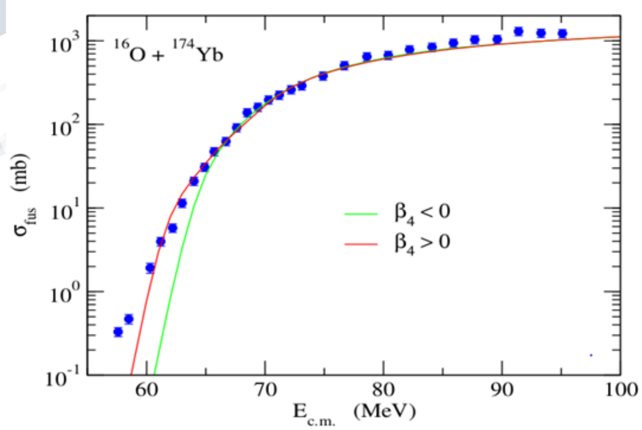

Fig.1: Fusion excitation functions with positive and negative hexa-decapole deformations on 16O+174Yb [2]

III. RESULTS AND DISCUSSION

First of all we carried out an intensive literature survey on the systems mentioned and anticipated the already performed experiments by J.O.Fernandez Niello et al. [4] and H.M. Jia et al.[5] during the theoretical coupled channel calculation by CCFULL[6]. Here we incorporated both quadrupole and hexadecapole combinations for the

16O+174,176Yb systems [Table 1] and the results are shown in Fig. 2. The Akyüz-Winther potentials were used in the calculations. The 3-state of 16O is also calculated in CC, a large change in cross section is observed. The 3- state of 16O should not be included due to its adiabatic property [7]. C. R. Morton et al. [8] claimed that higher-order deformations may have influences at low energy. I also include β6 couplings with its value of 0.02 by using an orientation-dependent deformed-target model, but little effects have been observed. The fusion cross sections measured by Niello et al.[5] is also incorporated, but with a very large cross section which demands a arbitrary division by 2.

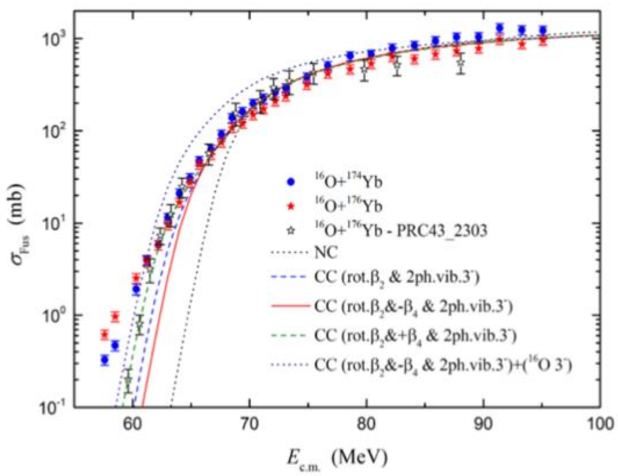

Fig.2: Fusion excitation functions on 16O+174,176Yb systems [both theoretical and experimental]

Table 1: The deformation parameters and excitation energies of different nuclei used in the CC calculations.

Nucleus	16O	174Yb	176Yb
E_{2+} (MeV)		0.076	0.082
E_{3-} (MeV)	6.13	1.381	1.491
β2,β4 (rot.) (MeV)		0.332, -0.050	0.304, -0.061
B_3 (vib.) (MeV)	0.733	0.051	0.024

During the fusion excitation measurement, 16O beam (with doubly magic and spherical) with pulse beam is bombarded on Ytterbium (Yb) within the energy range 64.6-103.6 MeV, which lead to formation of compound nucleus of 190,192Pt. We used two enriched Yb targets (with 99.99% and 96.93% purities for 174 and 176 isotopes) with carbon backing prepared by evaporation technique at IUAC target laboratory. The target thickness were measured by alpha energy loss method and inferred by Rutherford's back scattering. The part of the results on the systems is reported in T. Rajbongshi et al.[2] and one of the results is shown in Fig.3 below. The main finding of the result is that we observed a sub-barrier fusion enhancement and after fitting with the experimental data we were getting the new value of the hexa-decapole deformation as 0.020 (negative). Of-course, the barrier distribution on the systems were not found to be satisfactory because of the large amount of experimental uncertainty.

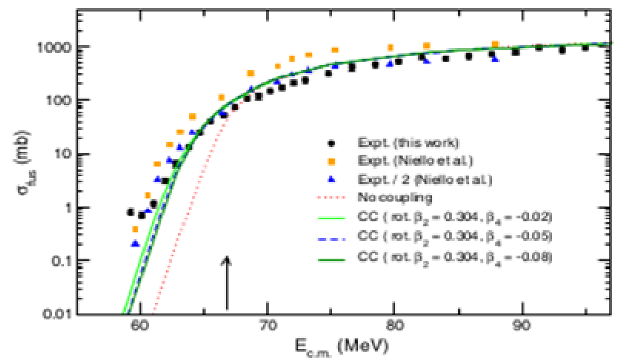

Fig.3: Fusion excitation function on 16O + 176Yb system measured at IUAC, New Delhi

Meanwhile, We were in doubt whether our experimental tool or recoil mass spectrometer were giving more error in the former measurement. In order to ensure it, we choose to perform the same experiment by quasi-elastic measurement at the back angles using the BARC-TIFR scattering chamber, Mumbai. This time 176Yb target with 96.63% enriched were used and thickness of target was 170 microgm/cm2 with a Carbon backing.

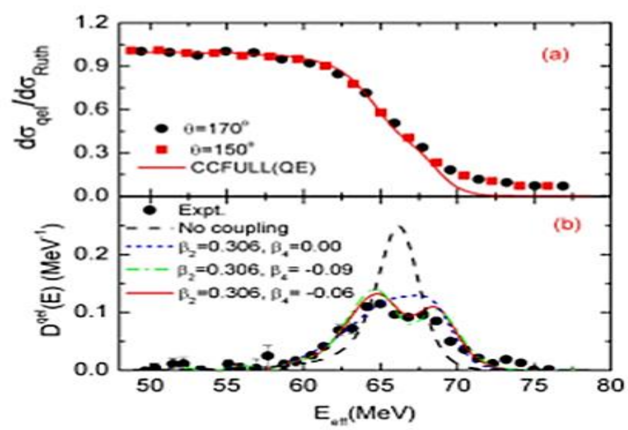

Fig.4: Quasi-elastic scattering cross section measured at back angles on 16O +176Yb at BARC-TIFR, Mumbai and its barrier distribution [7].

Four telescopic detectors having Silicon surface barrier detectors (~15+1500 microns) were placed at ±150 and ±170 degrees respectively with respect to beam direction. Two monitor detectors were put at ±20 degree for normalization purpose. The ratio of quasi-elastic scattering to Rutherford's scattering is being plotted in Fog.4 (a) and corresponding fitting of coupled channel calculation is shown by red continuous line. The corresponding barrier distribution with the deformation parameters are also shown in Fig.4(b) and the best fitting is found with hexadecapole deformation, β4=-0.06. Some part of the results is reported by G. Mohanto et al.[9]. SIn conclusion, fusion excitation functions and quasi-elastic scattering measurement was performed on 16O+174,176Yb systems and extracted the hexa-decapole deformation parameter from the fit of data and confirmed by coupled channel calculation. The values of are found to be β4=-0.020 and β4=-0.06 respectively in both the techniques. Therefore, both techniques are giving the different values which needs to be understood by more theoretical aspect. The barrier distribution for the later techniques is more consistent than the former.

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