Deformation effects on sub-barrier fusion cross sections in $^{16}O + ^{174,176}Yb$

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Background: Couplings with various reaction channels are known to enhance sub-barrier fusion cross sections by several orders in magnitude. However, a few open questions still remain. For example, the influence of higher order static deformations on sub-barrier fusion cross sections is yet to be comprehensively understood.
Purpose: We study the role of hexadecapole nuclear deformation effect on sub-barrier fusion cross sections. Also, this work aims to extract hexadecapole deformation (β_4) in nuclei in the lanthanide region.
Method: The evaporation residue (ER) excitation functions for $^{16}O + ^{174,176}Yb$ were measured at laboratory beam energies ($E_{\rm lab}$) in the range of 64.6–103.6 MeV. Measurements were carried out by employing the recoil mass spectrometer Heavy Ion Reaction Analyzer (HIRA) at IUAC, New Delhi. Fusion barrier distributions (BDs) were extracted from data. Results from the experiment were subjected to coupled-channels analysis, in which β_4 was varied as a free parameter.
Results: Experimental fusion cross sections at energies below the barrier expectedly showed strong enhancement compared to the predictions from the one-dimensional barrier penetration model. Data were satisfactorily reproduced after inclusion of negative β_4 for both the targets in the coupled-channels calculation.
Conclusions: The significant role of hexadecapole deformation was observed in the sub-barrier fusion of $^{16}O + ^{174,176}Yb$. The proposed value of β_4 reproduced the measured fusion excitation function reasonably well. The BDs from these data were also extracted but no definitive conclusions could be drawn from them.

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I. INTRODUCTION

Heavy ion-induced fusion reactions around the Coulomb barrier have been pursued quite intensely for the past few decades [1–4]. Fusion cross sections are found to be enhanced, in some cases by several orders of magnitude, over the prediction from the one-dimensional barrier penetration model near and below the Coulomb barrier [5,6]. The coupling of internal degrees of freedom such as transfer of valence neutrons, neck formation, zero point motion, and static deformation have been considered in order to explain observed enhancements of the fusion cross sections. The coupling with intrinsic degrees of freedom has an effect of changing the height of the barrier. Barriers lower than the one-dimensional Coulomb barrier are then responsible for the enhancement of fusion cross sections.

Deformation of one or both the reaction partners is known to enhance sub-barrier fusion cross sections [7–10]. The extent to which a particular degree of freedom (e.g., quadrupole or hexadecapole deformation) contributes to the sub-barrier fusion enhancement independently can be estimated by calculating the asymptotic energy shift [11] associated with that particular degree of freedom [12–14]. Besides, the idea that a positive β_4 could enhance sub-barrier fusion cross sections more, in comparison to what a negative β_4 does, was put forward for the reaction $^{16}O + ^{186}W$ [15]. On the other hand, due to negative hexadecapole deformations, enhancements of sub-barrier fusion cross sections have been measured for the reactions ^{16}O on $^{176,180}Hf$ and $^{182,184,186}W$ by Leigh *et al.* [16]. Also the same conclusion was drawn theoretically for the $^{16}O + ^{184}W$ system [17].

The barrier distributions (BDs) are known to be highly sensitive to higher order nuclear deformations. The experimental BDs can be obtained from the fusion cross sections [2,18] as well as from quasielastic scattering data [19,20]. The shapes of the experimental BDs extracted from the fusion excitation functions [9] for $^{16}O + ^{154}Sm$ and $^{16}O + ^{186}W$ reveal that the role of positive and negative β_4 is evident in the qualitative differences between the two BDs.

We performed an experiment to measure ER excitation functions for the systems $^{16}O + ^{174,176}Yb$ forming compound nuclei (CN) $^{190,192}Pt$ near and below the Coulomb barrier. Since ^{16}O is a doubly magic spherical nucleus, effects of nuclear shapes on fusion cross sections are expected to be solely due to target nuclei. We investigated the role of β_4 in reproducing fusion data with the help of coupled-channels (CC) calculations. The experimental details are described in Sec. II while analysis of data and results are presented in Sec. III. We summarize our work and conclude in Sec. IV.

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