

Surface polarization effect in reactions involving lanthanide and actinide targets

Rajni^{a,b}, Kirandeep Sandhu^c, M. K. Sharma^b, and Ajay Kumar Rai^a

^aDepartment of Physics, Sardar Vallabhbhai National Institute of Technology Surat, Gujarat

^bSchool of Physics and Materials Science,

Thapar Institute of Engineering and Technology Patiala, Punjab, India and

^cDepartment of Physics, GSSDGS Khalsa College Patiala, Punjab

Introduction

The deformation of colliding nuclei is responsible for the angular dependence of surface diffuseness that induces non-uniformity on the nuclear surface [1]. In the past, various methods have been employed to address the surface diffuseness of deformed nuclei in terms of gradient of the potential at the nuclear surface. Recently, Adamian et al [1] have investigated the same within lanthanide and actinide regions by using the microscopic Hartree-Fock (HF) + BCS calculations. As a result of this, a polynomial is obtained to estimate the surface polarization effects in the mentioned regions of periodic table.

Some of us [2] have used such parameterization to understand the surface polarization effects in the fusion dynamics of lanthanide targets (Tb and Sm). However, in the present study, the angle dependence in surface diffuseness is investigated in the reactions involving both actinide and lanthanide targets (and their isotopes) such as $^{18}\text{O}+^{218-249}\text{Bk}$ (actinide) and $^{18}\text{O}+^{146-194}\text{Nd}$ (lanthanide). The effect of deformation is incorporated by considering the prolate deformed target nuclei. The calculations are made within the Semi-classical based Skyrme Energy Density Formalism (SEDF) [3], where both the constant ($a(0)$) and angle dependent ($a(\theta)$) surface thickness parameters are considered. The present work is carried out by comparing the barrier characteristics (barrier height and barrier position) of colliding nuclei calculated using constant and angle dependent surface diffuseness parameters. The calculations suggest that with the inclusion of surface polarization effect the fusion barrier height V_B (and

position R_B) decreases more significantly for actinide targets as compared to that for lanthanide systems.

Theory

In Energy density formalism (EDF), the nuclear interaction potential $V_N(R)$ between colliding nuclei is defined as

$$V_N(R) = E_{tot}(R) - E_1 - E_2 \quad (1)$$

where $E_{tot}(R)$, E_1 and E_2 are the energy expectation values of composite and individual system, which are further obtained by volume integration of Hamiltonian density $H(r)$ as,

$$E(R) = \int H[\rho_p(\vec{r}), \rho_n(\vec{r})] d\vec{r}, \quad (2)$$

Here the SKRA force parameters [4] are used for the calculation of $H(r)$. $\rho_p(r)$, $\rho_n(r)$ are proton and neutron densities.

The nuclear density used in above equation is evaluated from the temperature dependent extended Thomas Fermi approach [5],

$$\rho_i(z_i) = \rho_{0i}(T) \left[1 + \exp\left(\frac{z_i - R_i(T)}{a_i(T)}\right) \right]^{-1} \quad -\infty \leq z \leq \infty \quad (3)$$

with $z_2 = R - z_1 = [R_1(\alpha_1) + R_2(\alpha_2) + s] - z_1$, and central density

$$\rho_{0i}(T) = \frac{3A_i}{4\pi R_i^3(T)} \left[1 + \frac{\pi^2 a_i^2(T)}{R_i^2(T)} \right]^{-1} \quad (4)$$

The Temperature and deformation dependent radius vector $R_i(T)$

$$R_i(T) = R_{0i}(T) \left[1 + \sum_{\lambda} \beta_{\lambda i} Y_{\lambda}^{(0)}(\alpha_i) \right], \quad (5)$$

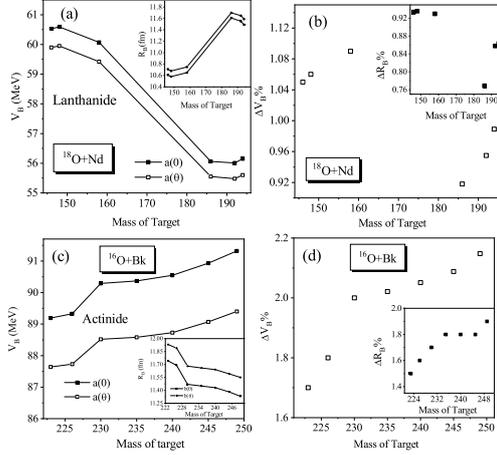


FIG. 1: Upper and lower panels show the variation of barrier height V_B (MeV) and barrier position R_B (fm) for lanthanide and actinide elements with respect to the mass of the target element.

here R_{0i} is the half density radii. The surface diffuseness parameters a_i is given by [6]

$$a_i(T=0) = 0.3719 + 0.0086A_i - 1.1898 \times 10^{-4}A_i^2 + 6.1678 \times 10^{-7}A_i^3 - 1.0721 \times 10^{-9}A_i^4 \quad (6)$$

The dependence of surface diffuseness a_i on angle θ is given by [1] as,

$$a(\theta) = a(0) + \Delta a(\theta). \quad (7)$$

with $\Delta a(\theta) = 0.25 \sin^2 \theta - 0.25 \sin^3 \theta$ for the lanthanides and $\Delta a(\theta) = 0.45 \sin^2 \theta - 0.40 \sin^3 \theta$ for the actinides. In Eq.(7), $a(0)$ is the constant surface diffuseness as defined in Eq.(6).

Calculations and Results

The upper and lower left panels of Fig. 1 show the variation of fusion barrier height V_B and fusion barrier position R_B (inset) respectively for lanthanide (Nd) and actinide (Bk) targets as a function of isotopic mass of the target nucleus. It is observed from upper panel of Fig. 1 that for the reactions with lanthanide (Nd) targets, the fusion barrier height V_B decreases and corresponding fusion barrier position R_B increases with the mass of

the target nucleus. The overall effect of angle dependence in surface diffuseness is such that it decreases the V_B (increases the R_B) as compared to the angle independent choice. However, in case of actinide targets, V_B is increasing and R_B is decreasing with the mass of the target nucleus. This is due to the difference in diffuseness parameter a value. For lanthanides, the value of a is increasing with mass number, as a result, V_B is decreasing. However opposite trend is observed for actinide targets. Moreover, the effect of angle diffuseness is more pronounced in actinides (see Fig.1(c)) in comparison to lanthanides (see Fig.1(a)).

The right panels of Fig.1 further depict the percentage deviation in V_B and R_B with and without the inclusion of surface polarization effect. One may observe that the maximum change in V_B and R_B for different isotopes of Nd is $\sim 1\%$ (Fig.1(b)), which on the other hand for the Bk is $\sim 2\%$ (Fig.1(d)). It means that the effect of surface polarization is almost double in actinide systems than for lanthanides. This clearly indicate the importance of angle dependent surface diffuseness in the fusion dynamics of considered reaction partners.

This work is supported by the Council of Scientific and Industrial Research (CSIR), New Delhi (File nos. 09/0677(11733)/2021-EMR-I; 09/1007(13391)/2022-EMR-I).

References

- [1] G. G. Adamian *et al.*, Phys. Rev. C **90**, 034322 (2014).
- [2] Rajni and M. K. Sharma, Int. J. Mod. Phys. E **28**, 1950052 (2019).
- [3] D. Vautherin and D. M. Brink, Phys. Rev. C **5**, 626 (1972).
- [4] M. Rashdan, Mod. Phys. Lett. **15**, 1287 (2000).
- [5] J. Bartel, M. Brack and M. Durang, Nucl. Phys. A **445**, 263 (1985).
- [6] L. R. B. Elton, *Nuclear Sizes* (Oxford University Press, London, 1961); H. de Vries, C. W. de Jager, and C. de Vries, At. Data Nucl. Data Tables **36**, 495 (1987).