Quasielastic scattering cross-section of ^{16}O + ^{92}Zr reaction

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Introduction

Nowadays, a great deal of attention has been attracted by the research around the Coulomb barrier on the fusion reactions and quasi-elastic scattering. The nucleus-nucleus interaction potential and the nuclear structure properties can be investigated by these kinds of heavy-ion collisions [1]. The nuclear structure properties of the collision partners can significantly affect fusion yields in sub-barrier domains. The involvements of various intrinsic degrees of freedom of the fusing pairs decrease the fusion barrier between participants and results in significantly larger fusion outcomes in comparison to the predictions of one dimensional barrier penetration model (BPM). In literature, it has been well established that the couplings between relative motion and intrinsic channels of the fusing partners cause splitting of single fusion barrier into a distribution of barriers of different heights and weights. This is known as fusion barrier distribution and the shape of fusion barrier distribution is quite sensitive to the type of couplings involved in the fusion process. The idea of fusion barrier distribution was given by Rowley *et al* [2] and it can be obtained by taking second order derivative of $E_{c.m.}\sigma_f$ with respect to center-of-mass energy. Also, large angle quasi-elastic scattering function can yield barrier distribution quite similar to the fusion barrier distribution and both fusion barrier distribution and quasi-elastic barrier distribution are practically same in their shapes. The quasi-elastic barrier distribution can be obtained by taking first order derivative of quasi-elastic scattering cross-section with respect to $E_{c.m.}$. It is well known that the fusion process can be interpreted in terms of penetration probability and is based on quantum mechanical tunneling while quasi-elastic scattering is related to reflection probability. The heavy-ion quasi-elastic scattering is considered as a sum of nuclear transfer process, inelastic scattering and elastic scattering (other than fusion process). In literature, it was emphasized that nuclear potential plays essential role in describing heavy ion collisions. It is studied thoroughly that nuclear potential is important for both fusion as well as quasi-elastic cross-section [3,4]. In other words, for description of fusion process and quasi-elastic scattering process nucleus-nucleus potential is required. In realistic systems, due to effects of nuclear distortion, the differential cross-section deviates from the Rutherford cross-section even at energies below the Coulomb barrier. In this regard, the quasi-elastic scattering cross-section depend upon angle of scattering as well as on nuclear distortion effects. The present work analyses the quasi-elastic scattering cross-section of ^{16}O + ^{92}Zr reaction by using symmetric-asymmetric Gaussian barrier distribution quasi-elastic scattering (SAGBDQELS) model.

From classical physics point of view, the projectile incident on target can either be elastically scattered or proceeds for fusion process. There exists a direct relationship between fusion cross section and elastic scattering differential cross section. The elastic scattering is directly related with the reflection probability (R_0) while fusion events are directly dependent on tunneling probability(T_o) so that sum of these is always equal to unity,

$$T_0 + R_o = 1 \text{ or } T_0 = 1 - R_0 \tag{1}$$

The energy derivative of eqn.(1) is defined as,

$$\frac{dT_o}{dE_{c.m.}} = 0 - \frac{dR_o}{dE_{c.m.}} \tag{2}$$

$$\frac{dT_o}{dE_{c.m.}} = -\frac{dR_o}{dE_{c.m.}} \tag{3}$$

Thus, the same information as extracted from the fusion cross section can also be extracted from quasielastic scattering cross-section. Thus, for $l = 0$, the contribution from the centrifugal potential term is zero. At $l = 0$, the

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ratio of $\frac{d\sigma^{el}}{d\sigma^{R}_{(E_{c.m.})}}$ $at\ \theta = 180$ degrees (backscattering angle) is equal to the reflection coefficient R_0. $\frac{d\sigma^{el}}{d\sigma^{R}_{(E_{c.m.})}}$ is defined as quasi-elastic scattering excitation function, where, σ^{el} and σ^{R} is cross-section for elastic scattering and Rutherford scattering respectively. Using semi classical perturbation theory, the ratio of $\frac{d\sigma^{el}}{d\sigma^{R}_{(E_{c.m.})}}$ is given by following relation,

$$\frac{d\sigma^{el}(E_{c.m.},\theta)}{d\sigma^{R}(E_{c.m.},\theta)} \sim 1 + \frac{V_N(R_C)}{ka}\frac{\sqrt{2\pi a_0 k\eta}}{E_{c.m.}} \quad (4)$$

with, θ= angle of scattering, $E_{c.m.}$ is the centre of mass energy, $k = \sqrt{2\mu E_{c.m.}/\hbar}$, μ being the reduced mass, and η is Sommerfeld parameter. In this work, total interaction potential between colliding nuclei is defined as,

$$V(R) = V_N(R) + V_C(R) \quad (5)$$

Here, V_N and V_C is nuclear and Coulomb potential, respectively. For spherical nuclei the Coulomb potential $V_C(R)$ is defined as, $V_C(R) = \frac{e^2 Z_P Z_T}{R}$ and the nuclear potential of the Woods-Saxon form is used, and is given by

$$V_N(R) = -\frac{V_0}{1+\exp\left[\frac{R-R_0}{a}\right]} \quad (6)$$

where V_0 is the potential depth, a_0 is the surface diffuseness parameter, and $R_0 = r_0(A_T^{1/3} + A_P^{1/3})$, where r_0 is rangeor reduced radius parameter, while A_T and A_P are the mass numbers of the target and projectile, respectively. The total interaction potential in eqn.(6) is evaluated at $R = R_C$, with R_C being the distance of closest approach. It is seen from eqn.(4), that the deviation of elastic cross-section from Rutherford one is sensitive to the surface region of the nuclear potential, especially to the surface diffuseness parameter (a_0) [5,6]. In SAGBDQELS model, to entertain the effects of nuclear distortion and possible channel coupling effects, Gaussian function is used as a weight function to eqn.(4) and total quasi-elastic scattering cross-section are obtained by weighting Gaussian function to $\frac{d\sigma^{el}(E_{c.m.},\theta)}{d\sigma^{R}(E_{c.m.},\theta)}$ (as given in eqn.(4)) and the results of calculations are shown in Fig.1.

Result and Discussion

For ^{16}O + ^{92}Zr reaction, the potential parameters are taken in such a way that the experimental data of given reaction can be reproduced. In this recent work, the parameters taken are: potential depths$(V_0) = 150\ MeV$; diffuseness parameter $(a_0) = 0.67\ fm$; range $(r_0) = 1.00\ fm$. The barrier characteristics such as barrier position $(R_B) = 9.54$; barrier height $(V_{CB}) = 44.82\ MeV$; barrier curvature $(\hbar\omega_B) = 4.00\ MeV$ are obtained by using above potential parameters. From Fig.1, one can easily notice that the theoretically calculated quasi-elastic cross-section reasonably reproduce the quasi-elastic cross-section data in whole range of incident energy.

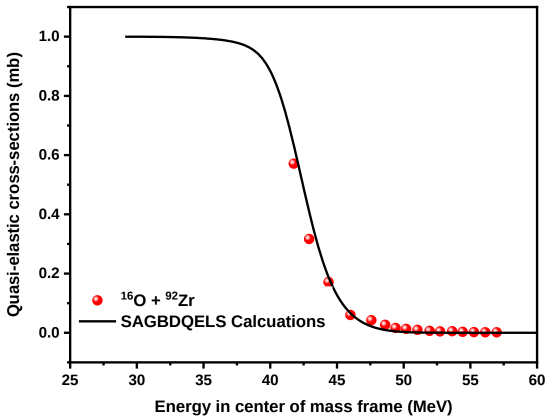

Fig. 1: Theoretical quasi-elastic scattering cross-section obtained from SAGBDQELS model is compared with the experimental results [7] for^{16}O + ^{92}Zr reaction as a function of $E_{c.m.}$.

Conclusion

In the attempt to study the quasi-elastic scattering, the quasi-elastic scattering process is investigated in the energy range $30\ MeV$ to $60\ MeV$. Theoretical representation of quasi-elastic scattering cross-section predicted by SAGBDQELS model is almost similar to the experimental findings and reasonably reproduced the experimental data of the studied system. It also demonstrates that the quasi-elastic scattering representation complement to various valuable information extracted from fusion process.

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