Statistical model analysis of fission fragment angular distributions for the system $^{16}O+^{181}Ta$

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(Received 12 August 2002; published 28 October 2002)

Fission fragment angular distributions have been measured for the fusion of ^{16}O with deformed ^{181}Ta target, in the energy range 90 MeV to 110 MeV. Combining with the existing data of evaporation residue and fission cross sections in the literature, the fusion cross sections have been determined in the range $1.1 \leqslant E/V_B \leqslant 1.6$. Detailed statistical model analysis of the entire data set has been performed and it has been shown that fission fragment anisotropies calculated are in good agreement with the experimental data. Even at the lowest energy studied, ($E=1.1V_B$) as there is good agreement between the data and the calculation, it can be concluded that the quasifission effect is negligible at this energy.

DOI: 10.1103/PhysRevC.66.047602 PACS number(s): 25.70.Jj, 24.10.Pa

The study of fission fragment angular distributions in heavy-ion induced fusion-fission reactions is of great current interest [1]. It has revealed in many instances, that the fission fragment anisotropy data measured from heavy-ion induced fission reactions could not be described by transition state model (TSM) [2]. Fast fission, quasifission, and preequilibrium fission are some of the noncompound nuclear processes proposed to describe these anomalous fission fragment anisotropy data. Back *et al.* [3], and Toke *et al.* [4] reported that for the reactions induced by heavy projectiles ($A_p \geqslant 20$), on various targets above the fusion barrier, the measured fission fragment angular anisotropies were larger than TSM predictions. This was explained in terms of quasifission model. The quasifission takes place for a composite system in which the unconditional saddle point (fission barrier) shape is more compact than the entrance channel contact configuration.

More recently fission fragment anisotropy data obtained from light projectile induced ($A_p \leqslant 20$) reactions on actinide targets could not be explained by TSM [1,5]. Hinde *et al.* [5] have provided an explanation of large near and subbarrier anisotropies by orientation dependent quasifission model for deformed actinide targets. According to this model, when the projectile encounters a prolate deformed target with the elongated tip, an elongated composite system with a narrow K distribution is formed and noncompound quasifission with large fragment angular anisotropy results. However, if it interacts with the equator (side) of the target, regular compound nuclear fission occurs. These effects are pronounced predominantly at near-barrier energies.

From the above two observations it is clear that there are two kinds of quasifission models. One due to Back *et al.* [3] proposed mainly for heavier projectiles ($A_p > 25$) and for $E \geqslant V_B$. The second one due to Hinde *et al.* [5] proposed for lighter projectiles and for $E \leqslant V_B$ [5]. For actinide targets it was pointed out by Sonzogni *et al.* [6] that if quasifission [5] was indeed responsible for anomalous values of anisotropy then the observed evaporation residue cross sections from the decay of the compound nucleus should also be suppressed. It is not very clear as to what is the bridge between normal fusion-fission and quasifission and at what beam energy such a transition should take place. It is interesting to extend this study to some other target and projectile combinations having large fission barrier. Heavy-ion induced fission with actinide targets are mainly dominated by first chance fission. However, for a less fissile system contribution from multichance fission becomes important. Even though lot of data exist for heavy-ion induced fission anisotropy on actinide targets, detailed measurements and consistent analysis of fission fragment anisotropy data for preactinide targets are rather scarce. All the above considerations necessitate further measurements of fission anisotropy for less fissile systems. With this motivation fission fragment angular distributions for ^{16}O fusing with a deformed ^{181}Ta target have been measured. To investigate the role of quasifission for such a preactinide-projectile system a detailed statistical model analysis of fission and evaporation residue cross sections and the fission fragment angular distribution data for $^{16}O+^{181}Ta$ system are reported. While carrying out this investigation the authors came across the fission angular distribution measurements of $^{16}O+^{182}W$ [7].This system is similar to the present system under investigation. comparison of this data with the present work is also made later in the text.

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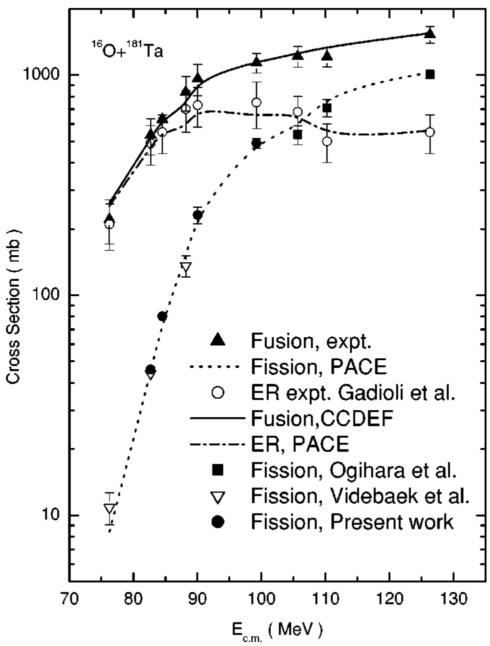

FIG. 1. The experimental excitation function for fusion, evaporation residue, and fission for $^{16}O+^{181}Ta$. The solid line is the CCDEF estimate for fusion, dot dash and dotted lines are PACE predictions for evaporation residue and fission, respectively.

Fission fragment angular distributions were measured for the present system in the energy range from 90 MeV to 110 MeV using the pelletron at Nuclear Science Center, New Delhi and the data were reported earlier [8]. Details of the experimental procedure can be found in Ref. [8]. Fragment angular distribution data in the energy range from 83 MeV to 96 MeV and from 115 MeV to 137.5 MeV exist in the literature [9,10]. Evaporation residue cross sections had been measured by Gadioli *et al.* by gamma ray activation technique [11]. Fusion cross sections have been obtained by summing evaporation residue and fission cross sections.

Fusion angular momentum distribution required for statistical model analysis was obtained by fitting the fusion excitation function using a simplified coupled channels code CCDEF [12]. Fission fragment angular anisotropy values were calculated using statistical model code PACE [14] and TSM [2]. Initial spin distribution of the decaying compound nucleus predicted from CCDEF was fed as input in PACE. Statistical model parameter k_f [scaling factor for rotating finite range model (RFRM) [13] fission barrier] and a_f/a_n (ratio of the level density parameter at the saddle point to that of equilibrium deformation) were adjusted to fit evaporation residue and fission cross sections. It is known that measured ER and fission excitation function can be fitted equally well by many pairs of k_f and a_f/a_n. However, each pair gives different chance distribution and altogether different fission anisotropy values [15–17]. These two parameters were again constrained by fitting the prescission neutron multiplicity data. Experimental neutron multiplicity data for this particular system is not available. However, neutron multiplicity data for a nearby system $^{19}F+^{181}Ta$ is available in the literature [17]. Further the neutron multiplicity calculated for this system by Baba's systematics [18] is more or less same as

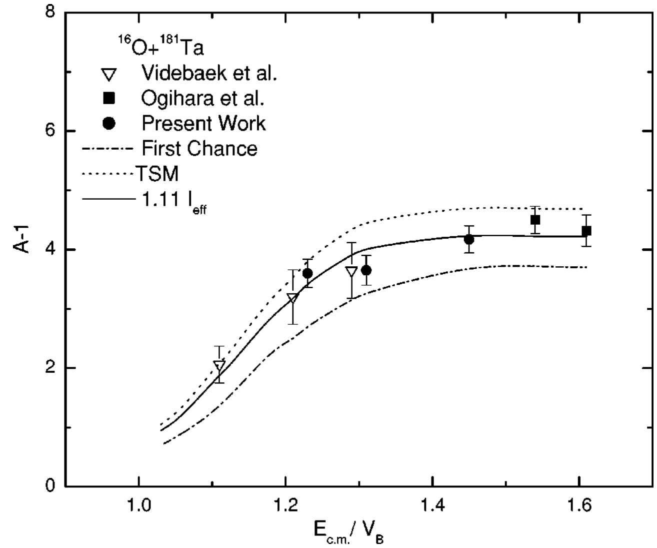

FIG. 2. The fission fragment anisotropy (A) data for $^{16}O+^{181}Ta$ are plotted as a function of $E_{c.m.}/V_B$. The dotted line represents multichance calculation. The continuous line is with normalized I_{eff} as indicated. The dot-dashed line is the calculation considering only first chance fission.

$^{19}F+^{181}Ta$ experimental data. Fits to the cross sections for fusion, evaporation residue and fission are shown in Fig. 1. Statistical model parameters used in the calculation were $k_f = 0.99$, $a_f/a_n = 1.012$. Fission fragment angular distributions were calculated for each chance fission separately and summed to get the cumulative angular distribution as discussed in Ref. [15]. RFRM [13] moment of inertia (I_{eff}) and rotational energy were used for calculating fission fragment angular distributions. It was found that use of RFRM effective moment of inertia over predict fission fragment angular anisotropies as observed in Refs. [15,19]. Hence, RFRM effective moment of inertia was scaled up by a factor 1.11 to

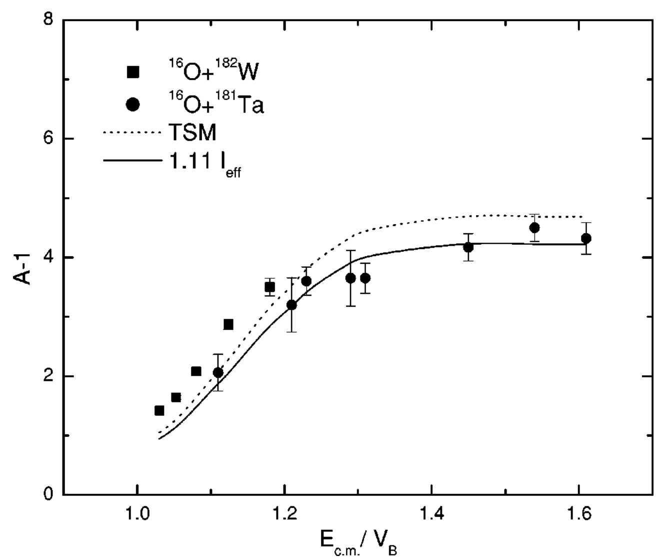

FIG. 3. Experimental data for $^{16}O+^{181}Ta$ are compared with that of $^{16}O+^{182}W$ at similar $E_{c.m.}/V_B$. The calculated curves are the same as in Fig. 2.

get agreement with the data over whole energy range (Fig. 2). It can be seen that with the above mentioned statistical model parameters, fission and evaporation residue cross sections are in good agreement with the calculation (Fig. 1). Suppression in the evaporation residue cross sections with respect to statistical model calculations was not observed. Fission fragment anisotropy data for $^{16}O+^{182}W$ reaction was compared with $^{16}O+^{181}Ta$ data. Ground state spin of ^{182}W is zero and corresponding value ^{181}Ta is 7/2. The difference between the two anisotropy data due to spin should show up in the $E_{c.m.}/V_B$ versus anisotropy plot (Fig. 3). Though the anisotropy data $^{16}O+^{182}W$ are on the average higher than the corresponding data of $^{16}O+^{181}Ta$, the difference in anisotropy values are not very pronounced. This observation is consistent with the simple scaling prescription proposed to account for target spin effects [20].

The reason for absence of orientation dependent quasifission in $^{16}O+^{181}Ta$, ^{182}W systems is not very clear. As mentioned earlier, for these systems multichance fission contributions are important, unlike the actinide target systems where first chance fission is the main component. It is generally observed that noncompound fission (quasifission, fast fission, and preequilibrium fission) is strongly influenced by the fission barrier B_f or B_f/T values of the fissioning composite system. In case of $^{16}O+^{181}Ta$, ^{182}W systems, the B_f values are relatively larger when compared to that for actinide target systems. Hence it may be conjectured that noncompound fission contributions will be lesser in these cases in comparison to actinide-projectile systems.

In summary, from this measurement and improved statistical model analysis with constrained statistical model parameters, it is concluded that fission anisotropy data for $^{16}O+^{181}Ta$ are in good agreement with the TSM calculation in the entire energy range. According to Hinde *et al.* [5], the quasifission effect is very pronounced at subbarrier energies and becomes progressively less important at above-barrier energies. In the present work, even at the lowest energy of $E=1.1\ V_B$, as there is good agreement between TSM calculation and the data (within error), it can be concluded that the quasifission effect is negligible at this energy.

The authors acknowledge the support of the pelletron accelerator staff of Nuclear Science Centre for the excellent beam quality throughout the experiment. Thanks are also due to Pradeep Barua for his help in various stages of the experiment.

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