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Measurement of fission anisotropy for ^{16}O+^{181}Ta

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Abstract. Anisotropies in fission fragment angular distributions measured for the system ^{16}O + ^{181}Ta over a range of bombarding energies from 83 MeV to 120 MeV have been analysed. It is shown that statistical transition state model (TSM) with pre-scission neutron correction described adequately the measured anisotropy data. Strong friction parameter is found to be necessary to estimate the pre-saddle to pre-scission neutron ratio.

Keywords. Fusion–fssion; saddle-point model.

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1. Introduction

The anisotropy observed in fission fragment angular distribution and its variation with incident energy has evolved as an important tool to probe the heavy ion induced fission process. Usually the fission fragment anisotropy data are analysed in the framework of statistical *transition state model* (TSM) [1]. The model provided an adequate description of a large set of data involving various target projectile combinations. However, deviations are observed in the anisotropy data at near barrier energy as well as above barrier energy ranges. A series of measurements of fission angular distributions for the systems with projectile mass $A_p > 20$ at energies above the barrier [2–5] have reported greater fragment anisotropy than expected from the standard theory. Similarly, at energies near the Coulomb barrier, the anisotropy data involving projectiles like ^{16}O and ^{19}F on many actinide targets with large deformations exhibit dramatic increase with decreasing energy [5]. In order to understand the data, an admixture of non compound reaction processes, like the fast fission, the quasifission with orientation dependence and the preequilibrium fission, is introduced as a source of fission like events along with the compound nuclear fission [2,5–9]. On the whole, the measured anisotropy data appear to depend on the entrance channel, the deformation and spin of the target, the mass of the projectile and the incident energy.

Another revealing aspect of fission fragment anisotropy is its dependence on the frictional force present in the compact shape of the compound nucleus at the saddle point. Assuming that only the pre-saddle neutron multiplicity, and not the pre-scission neutron multiplicity, controls the temperature of the compound system at the saddle, Frobrich *et al*

[10] have successfully removed the observed dicrepancy between the anisotropy data and the TSM calculation for ^{16}O + ^{208}Pb system. The strength of the frictional force required for the compact shape at the saddle actually determines the pre-saddle neutron multiplicity.

In this short presentation, we will report an analysis of the anisotropy data of ^{16}O + ^{181}Ta emphasizing the effect of neutron correction and the presence of the frictional force. The compound system ^{16}O + ^{181}Ta is of lower fissility and thus has larger fission barrier but the target ^{181}Ta has large deformation similar to many actinide targets for which enhanced anisotropies have been observed at near Coulomb barrier energies. The necessary data used in the analysis extends from beam energy of 83 MeV to 120 MeV. We have used the measurements of fission angular distributions at 83, 90, 96, 115 and 120 MeV from refs [12,13] along with data for 92, 98 and 108 MeV energies measured at the Pelletron, Nuclear Science Centre, New Delhi [11].

2. Analysis and results

The data for fragment anisotropies, given by $A = W(180^\circ)/W(90^\circ)$, are extracted from measured angular distributions for each energy by fitting the distributions with an exact expression of $W(\theta)$ [1]. The angle integrated fission excitation function is shown in figure 1.

An approximate expression for fission fragment anisotropy in the transition state saddle point model is: $A \approx 1 + \langle l^2 \rangle / 4K_0^2$ where $\langle l^2 \rangle$ is the mean-square angular momentum of the fissioning system and K_0^2 is the variance of the K distribution. K_0^2 can be explained in terms of effective moment of inertia $J_{\rm eff}$ at the saddle point as $K_0^2 = TJ_{\rm eff}/\hbar^2$. T is the temperature at the saddle point given by $T = \sqrt{E^*/a}$, where a is level density parameter taken to be $A/10$ throughout the calculation. The effective excitation energy at the saddle point is derived from the relation $E^* = E_{\rm cm} + Q - B_f(l) - E_{\rm rot}(l) - E_n$, where Q is the Q value of the compound nucleus formation. $B_f(l)$ is the l dependent fission barrier and $E_{\rm rot}(l)$ is the corresponding rotational energy (calculated from Sierk's model [14]). E_n is the energy removed by emission of pre-scission neutrons. In the calculation 10 MeV energy loss per neutron emission is assumed. The number of pre-saddle neutrons has been taken from the systematic measurements of Baba *et al* [15].

The mean square l-distribution $\langle l^2 \rangle$ of the compound nucleus is determined by fitting the experimental fission excitation function. Since for ^{16}O + ^{181}Ta, $\sigma_{\rm fission} < \sigma_{\rm fusion}$, the transmission coefficient $T_l(E)$ obtained from Wong's model [16] for fusion cross section is multiplied by the corresponding fission probability $P_f(l)$ to get the fission cross section. $P_f(l)$ is estimated from statistical model code PACE2. The resulting $\sigma_fus(l)$ is used to calculate the $\langle l^2 \rangle$.

In figure 2 a comparison of the data for the anisotropy of the fission angular distribution with the theoretical analyses is presented. The dotted curve in the figure represents the TSM calculation with neutron emission correction but assuming that all neutrons are emitted before the saddle. It is found that at lower energies fission fragment anisotropy is consistent with the saddle point model. At higher energies, however, the calculated value overestimates the experimental value. The reason may be attributed to our assumption that all the neutrons are emitted before the saddle point (that helps in *overcooling* the compound system at the saddle and thereby increasing the calculated anisotropy). Frobrich *et al* [10] suggested, from dynamical model calculation, that at above barrier energies more and more neutrons are emitted in the saddle to scission phase and hence these neutrons will not influence the temperature of the compound system at the saddle. We calculated the anisotropy incoporating the correction in estimating the excitation energy through the ratio of pre-saddle to pre-scission neutron multiplicities following Frobrich *et al*. The inclusion of the correction significantly improves the overall description of the data (solid curve in figure 2). The ratio of pre-saddle to pre-scission neutron multiplicits used in the calculation are shown in the last column of table 1.

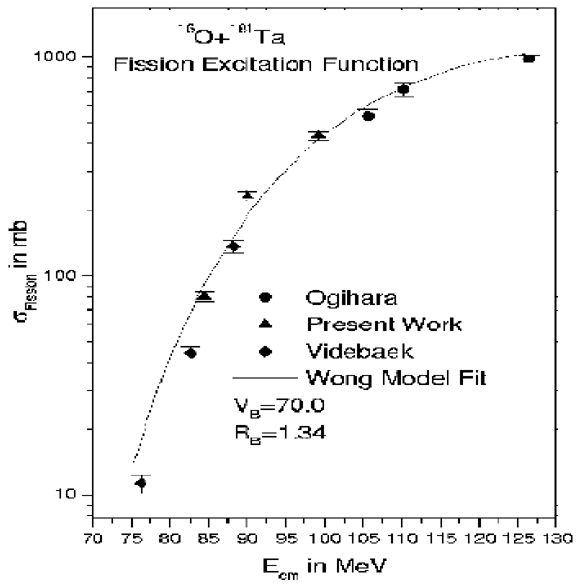

Figure 1. Fission excitation function for ^{16}O + ^{181}Ta.

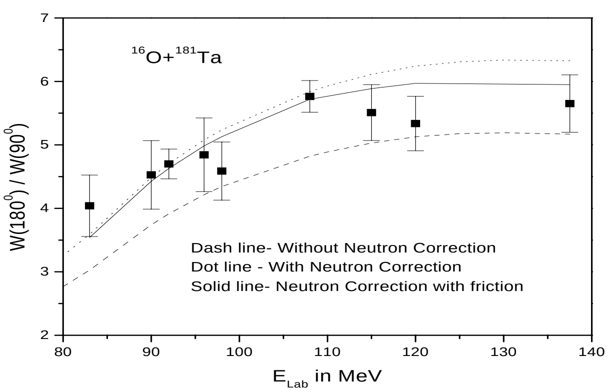

Figure 2. Fission fragment anisotropies for the system ^{16}O + ^{181}Ta.

Table 1. Summary of the results.

E_{beam} in MeV	σ_{Fiss} (mb) expt.	Anisotropy expt.	Anisotropy (without neutron correction)	Anisotropy (with neutron correction)	Number of pre-scission neutrons	Ratio of neutrons pre-saddle to pre-scission
[a]83	11±02	4.04±0.48	3.03	3.54	1.63	0.961
[a]90	44±05	4.53±0.54	3.74	4.43	1.91	0.944
92	80±09	4.70±0.24	3.92	4.63	1.99	0.939
[a]96	136±15	4.84±0.58	4.22	4.98	2.15	0.927
98	231±41	4.59±0.46	4.34	5.13	2.23	0.921
108	436±44	5.76±0.25	4.82	5.72	2.68	0.875
[b]115	536±53	5.51±0.44	5.03	5.89	2.78	0.860
[b]120	710±68	5.34±0.43	5.13	5.97	2.92	0.839

[a] From ref. [18]; [b] From ref. [19].

3. Summary

An analysis of anisotropy in fission fragment angular distribution in the energy range of 83 MeV to 120 MeV have been reported. The anisotropy data from near barrier to above barrier energies can be satisfactorily understood using the transition state model for fission that includes the correction for emission of pre-scission neutrons. However, the point of interest is the strength of friction for the compact shape of the compound nucleus at the saddle. To get the proper pre-saddle to pre-scission neutron ratio, in our calculation we require a strong friction parameter. A strong friction parameter will hinder the fission and enhance the production of evaporation residues. Simultaneous analysis of available evaporation residue cross sections with resulting friction parameter is in progress.

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