Entrance Channel Dependence of fusion-fission Dynamics in mass ~200 region

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Introduction

Quasi-fission process can easily be distinguished, at least conceptually, from the equilibrated fission process. The practical distinction, however, often hinges on the subtle differences in angular and mass distributions. While the mass distribution is nearly symmetric in both fission and quasi-fission processes the width of the mass distribution in quasi-fission is wider than that from the fission process signifying the non-equilibration in mass degree of freedom for the quasi-fission process. The angular distributions are also more strongly peaked along the beam axis in the quasi-fission reaction signifying its more direct nature.

However, some recent measurements indicate that broadening in the fission fragment mass distribution which is generally considered as a characteristic of quasi-fission, could be due to multi-chance fission as well. The angular [1,2] and mass distributions [3] of ^{12}C beam induced reactions on ^{232}Th target have shown no signature of quasi-fission, however, the mass distributions of ^{12}C + ^{235}U have shown broadening and 'flat top' nature at low excitation energies which has been attributed to late-chance fission. It indicates that there is an admixture of different modes of fission in these systems at low excitation energies.

There are different parameters, entrance channel mass asymmetry, target or projectile deformation, entrance and exit channel shell effects, etc which determine the dynamics of the nuclear reaction. There exist many contradicting experimental observations regarding the reaction dynamics using different probes, especially in mass ~200 region. We have selected two systems (^{16}O +^{181}Ta and ^{19}F +^{178}Hf) which are lying on either side of Businnaro-Gallone critical mass asymmetry to form the same compound nuclei (^{197}Tl) for our studies. We have measured the fission fragment mass distribution using Time of Flight method using Multi Wire Proportional Counters [5].

Determination of fission fragment mass distribution

The masses of the fission fragments can be obtained from the angle and time of flight information measured using MWPCs assuming symmetric fission of the Compound Nucleus with no particle emission before scission. From the measured time difference between complementary fragments and the path length of fission flight, fission fragment mass distribution can be obtained using the following relations from ref. 6.

$m_{CN} = m_1 + m_2$

$m_{CN} V_{CN} = p_1 \cos\theta_1 + p_2 \cos\theta_2$

$p_1 \sin\theta_1 = p_2 \sin\theta_2$

$m_1=[(t_1-t_2)+ t_0 + m_{CN} (d_2/p_2)]/[(d_1/p_1)+(d_2/p_2)]$

where t_1 and t_2 are the flight times of the complimentary fragments over flight distances of

d_1 and d_2. The momentum, polar angles and masses of the fragments are given by p_1 & p_2, θ_1 & θ_2 and m_1 & m_2 respectively. The velocity and mass of the compound nucleus is represented by V_{CN} and m_{CN}. t_0 is the constant involved in the system manly due to the electronics and other factors which can be deducted by assuming symmetric mass distribution of fission fragments. Mass resolution of the measurement is limited by the time resolution of the detecting system. In the present case, it depends on the intrinsic time spread of the beam bunch which is of the order of 0.9-1.5 ns.

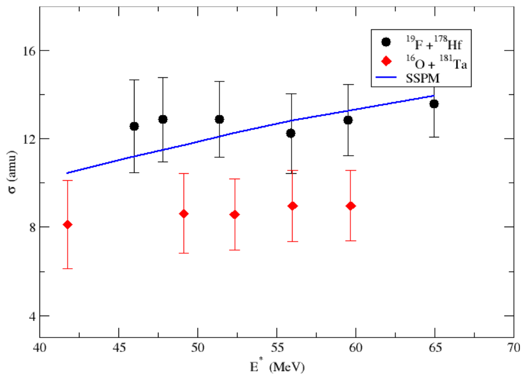

Fig 1. Variation of the standard deviation σ (amu) of the fitted mass distribution with excitation energy. The calculated widths are shown in (blue) continuous line.

Results and Discussions

The measured fission fragment mass width for both the systems under consideration are compared with the statistical model predications (Fig. 1). In the case of statistical fission of the equilibrated compound nucleus, the variance of the fission fragment mass distribution is a linear function of the nuclear temperature at the saddle point. The continuous (blue) line in Fig. 1 shows the calculated variance from statistical theory following the relation

$$\sigma=\sqrt{((T/k)+\beta l^2)}$$

where T is the temperature at the saddle point and k is the stiffness parameter for the mass asymmetry degree of freedom, $<l^2>$ the mean-square average of angular momentum and β is a constant of value 0.05[7]. The angular momentum of the CN was calculated by CCDEF[8] code. For the mass region under consideration the saddle to scission neutron emission is negligible and hence we have used the saddle point temperature (which is almost equal to the temperature at scission point) to calculate the mass variance. Temperature at saddle point is given by

$$T=\left[\frac{E*_{CN}+B_f(l)-E_{pre}-E_{rot}}{a}\right]^{1/2}$$

where E^*_{CN} is the excitation energy of the compound nucleus *Bf(l)* is the height of the fission barrier at angular momentum *(l)* , *Erot* is the rotational energy of the CN at the saddle point calculated using the finite range rotating liquid-drop model [9], *Epre* is the energy carried away by pre-scission neutrons, which is estimated from the empirical formalism given in ref [10], and *a* is the nuclear level density parameter.

Figure 1 shows a clear evidence of entrance channel dependence in the fusion-fission reaction process. It is to be noted that we have not observed any flat top or triple humped mass distribution at below Coulomb barrier energies. Further theoretical analysis and interpretation of the data is under progress.

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