Determination of $< \ell^2 >$ from fission fragment anisotropy for reactions involving weakly bound ^{6,7}Li projectiles

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Introduction

Fission fragment (FF) angular distributions for ^{6,7}Li+^{235,238}U reactions and FF mass distributions for ^{6,7}Li+^{238}U reactions have been measured at energies around the Coulomb barrier and reported in earlier symposia [1]. The aim is to investigate the effect of projectile breakup on various observables in fission reactions. Due to low breakup threshold there is a probability of breakup of the projectiles which in turn may affect the compound nucleus (CN) formation cross section. Effect of coupling of these breakup channels in addition to the inelastic and transfer channels is a topic of current interest. Tripathi *et al.* in their work on the measurement of $< l >$ for ^{7}Li+^{165}Ho reaction[2] have shown that the effect of breakup channel is coherent with inelastic or transfer channels. However, with many measurements on the complete fusion cross sections involving weakly bound projectiles providing different conclusions than above, the question of coherence or incoherence of the breakup coupling effect is still unresolved. Secondly, some of the breakup fragments may get captured by the target forming incomplete fusion followed by fission reaction and hence contaminate the compound nuclear fission yield. In this case, the inclusive fission data will carry the combined behavior of both CN and non-CN processes. Breakup fragments carrying only part of the incident projectile momentum form CN with reduced excitation energy and thus affecting the properties of the fission fragments. The moments of angular momentum e.g. $< \ell >$ and $< \ell^2 >$ of the CN which are interlinked with its formation cross section and angular momentum transfer to the target can provide information on different processes leading to the CN formation followed by fission reaction.

In the present study we propose to determine the $< \ell^2 >$ from the measured fission fragment anisotropy and compare them with the ones obtained from coupled channels calculations to investigate the effect of projectile breakup.

Determination of $< \ell^2 >$

Fission fragment angular anisotropy $A_{expt} = W(180^0)/W(90^0)$ ($W(\theta)$ being FF yield at angle θ) was obtained from the measured FF angular distributions [1] for ^{6,7}Li+^{235,238}U reactions. The mean square angular momentum $< \ell^2 >$ was derived from the above anisotropy using the relation $< \ell^2 >_{aniso}= (A_{expt} - 1)4K_0^2$, where $K_0^2 = (I_{eff}/\hbar^2)T$ is the variance of K-distribution (the projection of total angular momentum on fissioning axis). The value of $I_{eff}/\hbar^2$ was calculated by Sierk model [3] and normalized by a factor of 10/9 because the same factor was needed to reproduce the FF anisotropy for ^{10}B+^{232}Th reaction involving a tightly bound projectile and forms same CN as for ^{7}Li+^{235}U reaction. Same scaling factor was used for the other systems. The CN saddle point temperature was calculated from the relation $T = \sqrt(E^*/a)$ (with $a = A_{CN}/10$ MeV^{-1}). Excitation energy E^* at the saddle point is given by $E^* = E_{c.m.} + Q - B_f - E_{rot} - E_n$. Where Q is the Q-value for the formation of the compound nucleus. The spin dependent

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*Electronic address: `anamikaparihari.87@gmail.com` fission barrier B_f, ground state rotational energy E_{rot}, are also calculated using the Sierk model [3]. E_n is the average energy removed by the evaporated neutrons from the compound nucleus. The results for the $< \ell^2 >_{aniso}$ obtained from the measured anisotropy A_{expt} using the above relations are shown as hollow circles in Fig. 1.

Next we performed the coupled-channels (CC) calculations using simplified code CCFUS coupling only the target inelastic states. The barrier was adjusted to reproduce the high energy fusion cross sections. The static quadrupole and hexadecapole deformations of the target with $\beta_2 = 0.276(0.286)$ and $\beta_4 = 0.05(0.05)$ for ^{235}U (^{238}U) as available in the literature were coupled. The results for $< \ell^2 >_{CC}$ from CC calculations using the above parameters are shown as solid lines in Fig. 1. It can be observed that the $< \ell^2 >_{aniso}$ derived from the experimental anisotropy for all the systems are on an average higher than the ones calculated from CC calculations. It may indicate that the above difference between $< \ell^2 >_{aniso}$ and $< \ell^2 >_{CC}$ may be due to the effect of additional breakup or transfer channels which are not included in the CC calculations.

In a second method, following the prescription by C. V. K. Baba [4], $< \ell^2 >_{fiss}$ was obtained from the measured fission excitation function $\sigma(E)$ using the expression,

$$< \ell^2 > (E) = \frac{1}{\beta E\sigma(E)} \int_{-\infty}^{E} \sigma(E')E'dE' \quad (1)$$

where, $\beta = \hbar^2/2\mu R_b^2$ with μ being the reduced mass and R_b is the barrier radius of two interacting nuclei. The results shown by dashed lines also under-predict the $< \ell^2 >_{aniso}$.

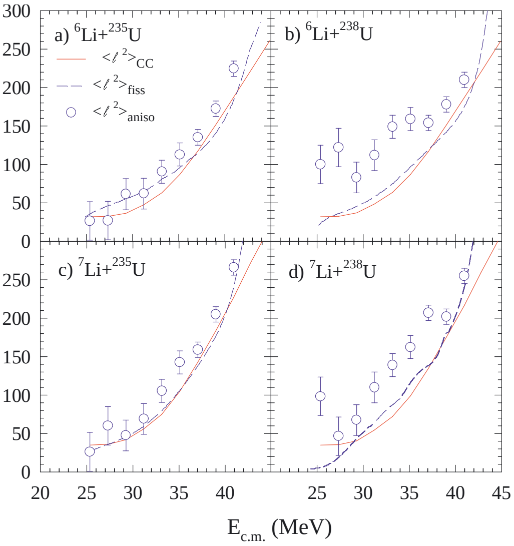

FIG. 1: Mean square angular momentum derived from FF anisotropy $< \ell^2 >_{expt}$ (hollow circles), obtained from CC calculations $< \ell^2 >_{CC}$ (solid lines) and from fusion fit by Baba's method[4] (dashed lines) for (a) ^{6}Li+^{235}U, (b) ^{6}Li+^{238}U, (c) ^{7}Li+^{235}U and (d) ^{7}Li+^{238}U reactions.

Qualitatively one can understand the difference between $< \ell^2 >_{aniso}$ and $< \ell^2 >_{CC}$ or $< \ell^2 >_{fiss}$ as follows. Due to the presence of non-CN (breakup/transfer induced) fissions a correction is needed in the value of $K_0^2 = (I_{eff}/\hbar^2)T$ which is used for calculating $< \ell^2 >_{aniso}$. Assuming the normalization of I_{eff} with respect to the calibration reaction ^{10}B+^{232}Th to be correct, the value of T which is calculated based on complete fusion-fission needs modification due to non-CN fission contribution involving incomplete momentum transfer. Thus, the effective temperature T_{eff} at the CN saddle point should be lower and so also the value of K_0^2, which in turn will scale down the values of $< \ell^2 >_{aniso}$ bringing them closer to the $< \ell^2 >_{CC}$ and $< \ell^2 >_{fiss}$. On the other hand, the effect of breakup coupling on $< \ell^2 >_{CC}$ needs to be investigated.

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