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Effect of Angular Momentum Variation in Heavy Ion Induced Fusion Reaction

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Introduction

Two-body collisions have become an area of interest for most researchers at the present time, they have been investigated and studied extensively [1–9]. In low-energy nuclear reactions above the coulomb barrier, a variety of non-equilibrium nuclear dynamics can be studied, such as energy dissipation, nucleon transfer, the shape of the evolution of the compound nucleus in a heavy ion fusion reaction, and so on. The completely fused compound nucleus releases evaporating neutrons, charged particles, and finally a cascade of γ-rays. In the light and medium mass systems, it is relatively straightforward to identify events associated with complete fusion by measuring the evaporation residues. Alternatively, the characteristic γ-rays emitted in the last step of this decay chain can be measured to identify a fusion event.

Research has improved several theoretical frameworks that are currently in use and that specifically take into account the dynamics of nucleus-nucleus interactions. Some of them include the statistical model (CASCADE) to calculate fusion cross-sections and the optical model for elastic scattering [10]. The user interface of many code developed in the Fortran programming dialect is complex; as a consequence, investigators must carefully prepare input files, that will include many lines. In other words, executing these codes would be extremely challenging for a non-expert user, who would therefore squander time.

In experimental nuclear reaction evaporation spectra of light particles from the compound nucleus help us to know about the reaction dynamics [1–3, 7]. Based on dynamical calculations of the trajectories in a multidimensional space, the geometrical shapes of the system from the initial approach of two separated spherical nuclei are described. Through the mononucleus regime, until either fusion or reseparation of two final fragments was observed, the early description of the heavy ion dynamics that lead to the diversion of a significant portion of the reaction cross section into deep-inelastic and quasi-fission channels was developed.

Plenty of investigations have been carried out regarding heavy-ion fusion reactions, and it has been demonstrated that these reactions depend on the entrance channel characteristics [4–9], including the mass asymmetry of the entrance channel, the excitation energy, the angular momentum, and the Z_PZ_T (charge product of the projectile and target), etc. To examine the nucleus at high spin or high temperature, fusion reactions are useful tools, and the dissipative evolution of compound nuclei is an active area of research in heavy ion induced fusion reactions. In such reactions, the colliding nuclei possess a certain amount of intrinsic angular momentum.

Dynamical Model Calculation

The original idea of macroscopic dissipative dynamics was included by H. Feldmeier in the particle exchange reaction model HICOL [3]. This model also determines the period required for the system's various degrees of freedom to achieve equilibrium. The analysis of the dynamical variation in the shape of the compound nucleus and the dissipation process in the entrance channel leads to the delayed formation time in composite systems. In this model, two spherical nuclei are likely connected by conical forms, which dynamically change in a series. To ascertain the temporal evolution of the collision dynamics, the target-projectile system becomes caught in the dip of the fusion potential while undergoing the fusion reaction, and the dinuclear combination drifts along the mass asymmetry coordinate through the mass exchange to produce a fused nucleus. The total charge, orbital angular momentum, and mass asymmetries of the fusion system play an essential function in determining the dynamical barrier for the initiation of fusion and the Langevin equation which includes a dissipative, fluctuating force is solved [7].

$$\frac{dp}{dt} = -\frac{dT}{dq} - \frac{dV}{dq} + X(t)\ , \quad \frac{dq}{dt} = \frac{p}{M}\ ,$$

where V stands for the conservative potential, T= $\frac{p^2}{2M}$ signifies the collective kinetic energy, and M implies the mass tensor. $X(t)$ is the fluctuating force driven by the coupling of the collective degrees of freedom to the intrinsic degrees of freedom. By assuming the incompressible and irrotational flow of mass during the shape evolution in the collision, the mass tensor can be obtained from the profile function.

In the realm of super heavy mass, it has been extensively employed to examine fusion and fission events. The relevance of the neck behavior of the colliding system has been captured in code, which shows how appropriate processing of the mass parameter for the neck degree of freedom can reduce the theoretical overestimation of fusion probability in heavier colliding systems. The impact of the entrance channel mass asymmetry ($\alpha=(A_t - A_p)/(A_t + A_p)$) in the fusion kinetics of heavy ion-induced events has been a focus of various theoretical and experimental calculations [2–4] in the past.

Results and discussion

In this study, we have calculated the variation of compound nucleus formation time with the angular momentum as shown in Fig. 1 for the two different reactions that make the same compound nucleus. The dynamical model code HICOL is employed to calculate the formation time of a compound nucleus at different values of angular momentum.

In this realm, we have shown that when the angular momentum value is low, both reactions have nearly the same formation time, but when we increase the value of excitation energy, angular momentum value increases due to which a huge difference occurs in their formation time. Also, we observe that symmetric reactions result in a more dissipative evolution of the compound nucleus than an asymmetric system. From Fig. 1, it is clear that the compound nucleus (^{107}In*) formed through ^{51}V + ^{56}Fe →^{107}In* has a long formation time compared to the ^{32}S +^{75}As→^{107}In* which indicates the dissipation in the nuclear reaction during compound nucleus formation, because angular momentum may prevent the energy from being transferred to other degrees of freedom and nuclei in collision experience more distortion at high angular momentum.

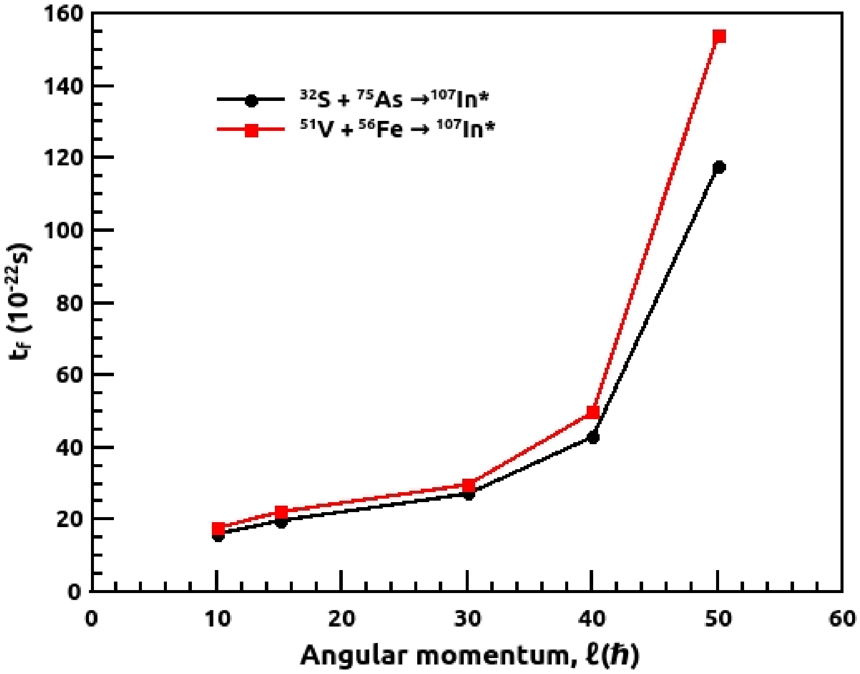

Fig.1. The influence of angular momentum on compound nuclear formation time.

The equations of motion are solved for a given angular momentum to determine the time development of various macroscopic variables. Fig. 2 depicts the relationship between σ (Neck Coordinates) and time for various angular momentum values. We observed that the time evolution of the neck coordinate exhibits varied behavior for the ^{51}V + ^{56}Fe reaction and quite distinct behavior for the ^{32}S + ^{75}As reaction. For the ^{51}V + ^{56}Fe system, the large value of neck coordinates (σ) indicates that the system has a more elongated shape for composite system than ^{32}S + ^{75}As.

Summary

After a general discussion about angular momentum variation with the macroscopic variables of composite systems in heavy ion fusion dynamics, it was observed that angular momentum affects the evolution of the compound nucleus in symmetric as well as asymmetric systems. It means that both systems have the dissipative evolution of the compound nucleus, but the symmetric system takes more time to evolve than the asymmetric system. In this series, we have also observed that the neck coordinate is also influenced by the variation of angular momentum due to which symmetric systems have a more elongated shape than the asymmetric systems. The variation of angular momentum will be beneficial for the study of reaction dynamics.

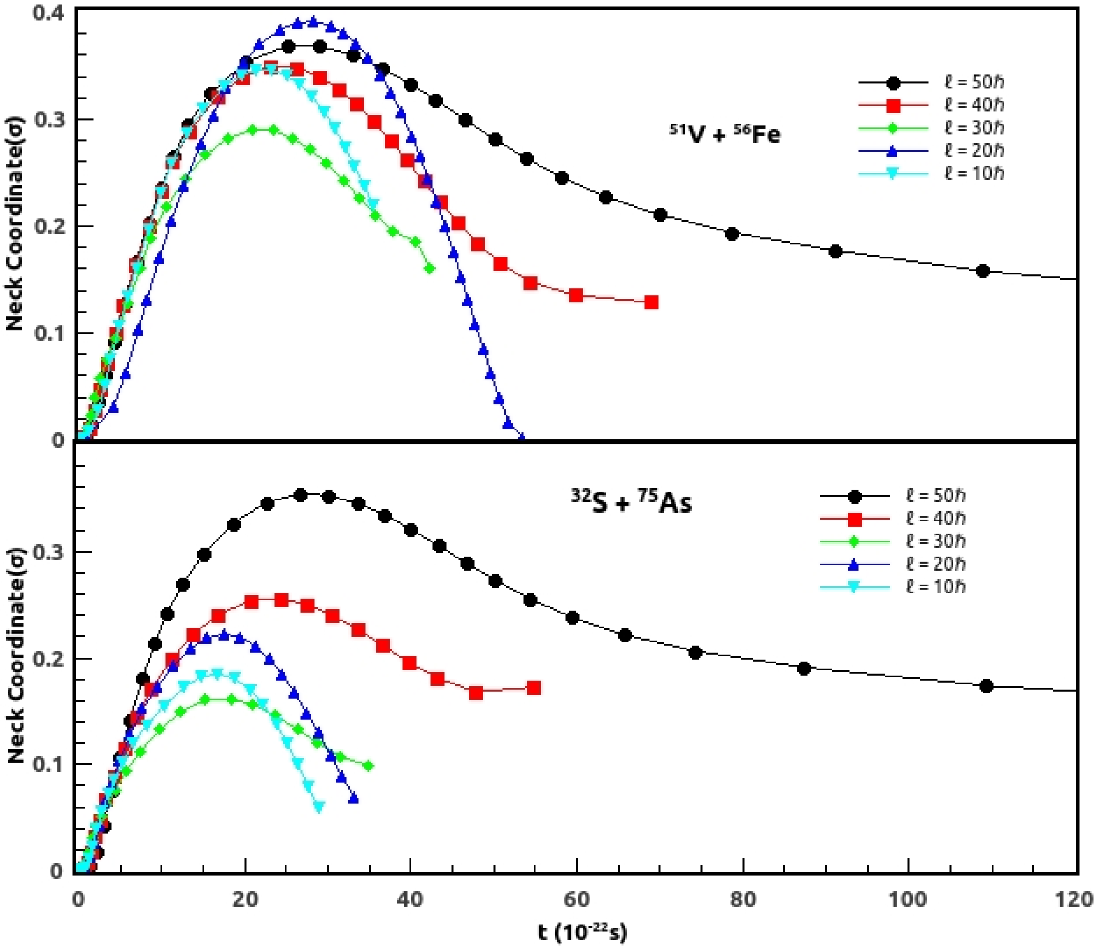

Fig.2. Neck coordinates as a function of time evolution of compound nucleus formation.

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