HICOL model calculations for medium mass systems at above barrier energies

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Introduction

In recent studies the role of dynamical effects on the fusion has been emphasized [1]. It is observed that at above barrier energies the fusion process is hindered [2]. In case of mass symmetric systems, the fusion is hindered because of the long formation time of the compound nucleus. This implies that entrance channel plays an important role in the fusion reactions.

The observed deviations in the statistical model due to long formation times can be explained by taking dynamical effects into consideration. According to which the formation of compound nucleus takes around 10^{-21} sec to form, which is comparable to the decay time for the compound nucleus. As a result of this, the higher partial waves do not contribute to fusion in case of symmetric systems.

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Theoretical Calculations

In this contribution we present HICOL model (which is a dynamical model) calculations for several medium mass systems [3]. This model explains the dynamical evolution of two colliding nuclei as a sequence of steps. The intermediate di-nuclear compound formed can be described by three parameters, viz Δ, the asymmetry parameter; s, elongation; and σ, the neck coordinate.

s = distance between two spheres

$$\Delta = \frac{R_1 - R_2}{R_1 + R_2},$$

$$\sigma = \frac{V_0 - \frac{4\pi}{3}R_1^3 - \frac{4\pi}{3}R_2^3}{V_0},$$

where V_0 is the volume of nuclei, and R_1 and R_2 are the radii of the target and the projectile respectively.

As a representative case we present the systems ^{48}Ti + ^{48}Ti and ^{27}Al + ^{69}Ga, in which the time evolution of partial waves with **s** have been calculated and plotted using HICOL code. Both populate ^{96}Ru compound nuclei. The results are shown in Fig 1.

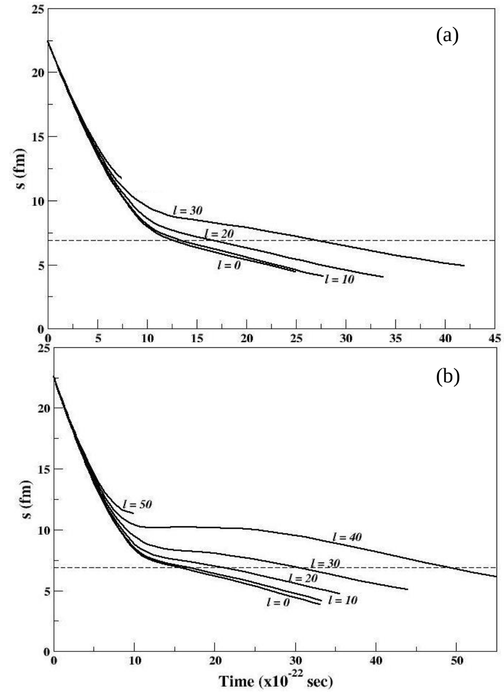

Fig. 1 Calculated evolution of the separation 's' of colliding nuclei as a function of time for (a) asymmetric reaction ^{27}Al + ^{69}Ga at E_{lab}=93 MeV. (b) symmetric reaction ^{48}Ti+^{48}Ti at E_{lab}=155 MeV. The dashed line corresponds to $s = s_{crit}$.

In these calculations, s_{crit} is taken to be equal to the radius of compound nuclei formed, which is given as $R=R_0A^{1/3}$. The highest partial wave that will lead to fusion, as predicted by the classical model for ^{27}Al + ^{69}Ga and ^{48}Ti + ^{48}Ti

Table 1: HICOL calculations compiled for various systems along with other parameters.

S.No.	System	Asymmetry Parameter	E_{lab} (20% Above Barrier) (MeV)	l_{max} (ħ)	HICOL predicted l (ħ)	Formation Time (sec) (x 10^{-21})	Decay Time (sec) (x 10^{-21})
1	$^{27}Al + ^{69}Ga$	0.067	93	50	40	2.52	4.25
2	$^{48}Ti + ^{48}Ti$	0.000	155	58	30	7.05	7.00
3	$^{13}P + ^{27}Al$	0.120	80	30	20	1.78	4.07
4	$^{58}Ni + ^{64}Zn$	0.016	235	83	50	5.43	6.30
5	$^{58}Ni + ^{65}Cu$	0.019	224	74	40	4.34	5.46
6	$^{35}Cl + ^{64}Zn$	0.099	125	57	30	1.57	3.89
7	$^{35}Cl + ^{65}Cu$	0.102	120	57	40	2.56	3.96
8	$^{32}S + ^{156}Gd$	0.256	166	90	50	4.35	5.20
9	$^{58}Ni + ^{96}Zr$	0.083	245	104	60	8.05	11.90
10	$^{28}Si + ^{27}Al$	0.006	71	28	20	2.01	2.41

are respectively l_{max} = 50ħ (E_{lab} = 93 MeV) and l_{max} = 58ħ (E_{lab} = 155 MeV).

Summary of the HICOL calculations for various medium mass systems is presented in Table 1. Decay times were estimated using PACE [4] calculations while the formation times were estimated from HICOL calculations.

Conclusions

It can be seen from the Fig 1 of the considered test systems, that the higher l values do not lead to the spherical trajectories in case of the symmetric system $^{48}Ti + ^{48}Ti$ and remain elongated for a long time. Also it is clearly illustrated that the formation time for the asymmetric system $^{27}Al + ^{69}Ga$ is much less than that of $^{48}Ti + ^{48}Ti$. This indicates that there is a gradual increase in the formation time of the compound nucleus as one goes from the asymmetric to the symmetric systems in the entrance channel. This is in agreement with the fact that symmetric systems evolve much slowly in comparison to asymmetric systems. We can see from Table 1 that a completely symmetric system has $\Delta = 0$. As Δ increases, so does the asymmetry parameter for a particular system. The formation time is less than the decay time in case of asymmetric system, while in case of symmetric system both are comparable. Therefore the influence on particle decay during the formation process of the compound nucleus will be significant in case of symmetric system. While in case of asymmetric system, much evaporation will not take place.

Classically calculated l_{max} values along with the HICOL predicted l values are also presented in the above table. It can be seen that in all the cases the partial waves actually leading to fusion is lower than those predicted by statistical model.

References

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