Dynamical aspects of fusion enhancement for neutron rich compound systems

Rupinder Kaur[1,2,*] Varinderjit Singh[2], Maninder Kaur[2], Sarbjeet Kaur [3], BirBikram Singh[3], and B.S. Sandhu[1]
[1]*Department of Physics, Punjabi University, Patiala-147002, India.*
[2]*Department of Physics, I.K.G. Punjab Technical University, Kapurthala-144603, India. and*
[3]*Department of Physics, Sri Guru Granth Sahib World University, Fatehgarh Sahib-140406, India.*

Introduction

Understanding the mechanism of fusion of neutron rich systems has importance not only in the nuclear reactors and production of heavy elements but also in the astrophysical scenarios. Various experimental measurements have suggested an enhancement of fusion probability as compared to standard statistical model at near barrier energies for such systems [1]. Various authors have also indicated the presence of strong isotopic dependence of the fusion cross sections near the barrier. These studies have established the importance of interplay between nuclear structural and reaction dynamical aspects present in these many-body systems. The enhancement of fusion cross sections observed through these isotopic chains of nuclear reactions is being considered as one of the best methods to understand the character of neutron rich matter. The existence of these experimental studies motivates to investigates the dynamical aspects associated with the fusion reactions of the neutron rich nuclei. The present work investigate the fusion dynamics involved in the isotopic chain of reactions ($^{39,40,41,47}K+^{28}Si$) to explore the effect of neutron number on fusion enhancement at near barrier energies.

Methodology

The Dynamical cluster decay model (DCM) [2] of Gupta and collaborators is worked out in terms of collective co-ordinates of mass (and charge) asymmetries. In terms of above said co-ordinates, for ℓ-partial waves, the compound nucleus decay cross-section is given by

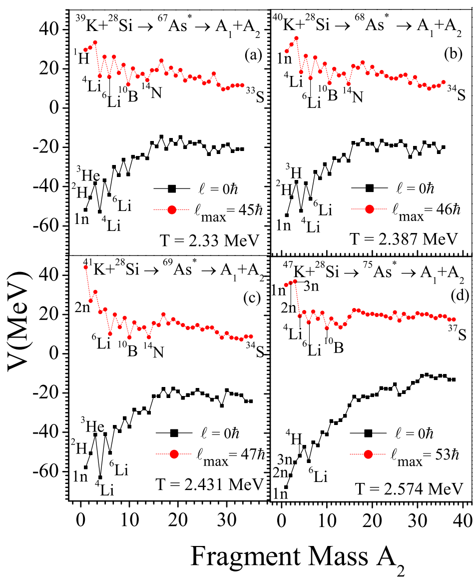

FIG. 1: The fragmentation potential V(MeV) as a function of fragment mass number (A$_2$), calculated for two extreme ℓ -values, for the compound systems $^{67,68,69,75}As^*$ at E_{cm}= 36.8 MeV

$$\sigma = \frac{\pi}{k^2}\sum_{l=0}^{l_{max}}(2l+1)P_0P; \qquad k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \tag{1}$$

Where, $\mu = [A_1 - A_2/(A_1 + A_2)]m$, is the reduced mass, with m as the nucleon mass and ℓ_{max} is the maximum angular momentum. Where P is the barrier penetration probability and P_0 is the preformation probability at a fixed R on the decay path. The P_0 are evaluated by solving stationary Schrödinger wave equation and P calculated as the WKB tunneling probability.The structure information in

*Electronic address: `roopisaini87@gmail.com`

TABLE I: The experimental and DCM calculated σ_{Fus} of CN $^{67,68,69,75}As^*$ at different values of $E_{c.m.}$.

Reaction	$E_{lab}(MeV)$	$E_{c.m.}(MeV)$	$E^*_{CN}(MeV)$	T (MeV)	$\ell_{max}(\hbar)$	ΔR (fm)	σ_{Fus} DCM	σ_{Fus} Expt
^{39}K +^{28}Si→ ^{67}As*	88.05	36.8	38.15	2.33	45	1.075	9.0	7.7±1.27
	89.6	37.4	38.78	2.351	44	1.15	21.35	21.3±3.96
	94.27	39.4	40.68	2.406	43	1.3	131.5	127.0±12.4
	101.69	42.5	43.78	2.493	43	1.375	257.1	265.0±31.6
^{40}K +^{28}Si→ ^{68}As*	89.37	36.8	40.67	2.387	46	1.075	12.0	-
	95.92	39.5	43.37	2.463	47	1.3	144.0	-
	103.21	42.5	46.37	2.5444	47	1.375	262.0	-
^{41}K +^{28}Si→ ^{69}As*	90.68	36.8	42.85	2.431	46	1.075	14.2	-
	97.33	39.5	45.56	2.504	47	1.3	146.2	-
	104.73	42.5	48.55	2.58	47	1.375	264.0	-
^{47}K +^{28}Si→ ^{75}As*	98.57	36.8	52.64	2.574	53	1.075	40.0	34.0±5.63
	100.44	37.5	53.33	2.591	51	1.15	66.22	63.6±12.1
	105.80	39.5	55.33	2.638	50	1.3	213.6	177.0±29.4
	114.10	42.6	58.44	2.708	50	1.375	361.9	327.0±35.6

P_0 enters through the fragmentation potential $V(\eta, R)$ as shown in Fig. 1 [2].

Calculations And Discussions

The calculations have been performed within the DCM for an isotopic chain of reactions $^{39,40,41,47}K +^{28} Si$ with quadruple deformed nuclei having compact configurations.The experimental fusion cross-sections, σ_{Fus} for $^{39,47}K +^{28} Si$ reactions have been reproduced using neck length parameter ΔR, the only free parameter of DCM. The DCM calculated σ_{Fus} for both $^{39,47}K +^{28} Si$ reactions give a good agreement with the experimental cross-sections for same value of ΔR having same center-of-mass energies (Ec.m.), as summarized in the Table I. In view of this, σ_{Fus} for $^{40,41}K +^{28} Si$ reactions, at same Ec.m., have been predicted using these ΔR values.

It is observed that the σ_{Fus} increases for the reactions induced by the more and more neutron-rich isotope of K. The increase in the fusion cross-sections at energies well above barrier may be attributed to the increase in the size of compound nucleus whereas the increase in the cross sections near barrier may be due to the dynamics involved in the fusion. The enhancement in σ_{Fus} is more as one move from ^{39}K to ^{40}K as compared to the movement from ^{40}K to ^{41}K. This can be explained by considering number of neutrons in K isotopes. While going from ^{39}K to ^{40}K one moves from a nucleus with paired neutron to an unpaired neutron nucleus whereas for the case of ^{40}K to ^{41}K the transition is from unpaired to paired neutron nucleus. Hence, one can conclude that the presence of an unpaired neutron results in a larger fusion enhancement as compared to paired neutron. This work motivate planning of experiments to validate these observations.

References

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