An attempt to explore the fusion of light and mid-mass nuclei away from β stability line

Varinderjit Singh[1,2],* J.E. Johnstone[2], R. Giri[2], S. Hudan[2], J. Vadas[2], R. T. deSouza[2], Z. Lin[2], C.J. Horowitz[2], D. Ackermann[3], A. Chbihi[3], Q. Hourdille[3], A. Abbott[4], C. Balhoff[4], A. Hannaman[4], A. B. McIntosh[4], M. Sorensen[4], Z. Tobin[4], A. Wakhle[4], S. J. Yennello[4], M. A. Famiano[5], K. W. Brown[6], C. Santamaria[6]

[1]*Department of Physical Sciences, I. K. Gujral Punjab Technical University, Kapurthala - 144603, INDIA*
[2]*Deptartment of Chemistry and Center of Exploration of Energy and Matter, Indiana University, Bloomington, Indiana - 47408, USA*
[3]*GANIL, 1 Henri Becquerel Blvd., Caen – 14000, France*
[4]*Physics Department, Cyclotron Institute Texas A & M University, College Station, Texas – 77843, USA*
[5]*Department of Physics, Western Michigan University, Kalamazoo, Michigan – 49008, USA*
[6]*Physics National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan – 48824, USA*

· * *email: vickymangat3@gmail.com, Mangat_phy@yahoo.co.in*

Fusion of nuclei away from β stability line provide a number of interesting observation, which cannot be explained using present understanding of the theoretical models. This presentation summaries the observations by investigation of fusion of $^{10-15}C + ^{12}C$, $^{39,41,45,47}K + ^{16}O$ and $^{36,44}Ar + ^{16}O$ reactions in both light and mid-mass regime. Time-dependent Hartee-Fock model fails to explain the experimental observations of $^{x}C + ^{12}C$ systems and indicated that neutron dynamics play a larger role than accounted in TDHF calculations presently. On the other hand in $^{x}K + ^{16}O$ reactions the effect of shell closure in beam is observed on the fusion excitation function.

1. Introduction

Fusion of nuclei away from line of stability has importance in understanding nuclear Astro-physics and also play a vital role in understanding of nature of nuclear matter. Astro-physics is the main reason behind the investigation of neutron-rich nuclei as it is important in understanding of various phenomena such as origin of elements, neutron star composition, neutron star-neutron star merger events, X-ray super-bursts and many more. In the nuclear physics investigation of nuclei away from stability line provides an opportunity to check the validation of different theoretical models and also provide new experimental data to improve the model to explain the nuclear matter away from stability. With a motivation to understand the fusion of the exotic nuclei, the fusion of $^{12-15}C + ^{12}C$ [1], $^{39,41,45,47}K + ^{16}O$ and $^{36,44}Ar + ^{16}O$ [2] have been investigated.

2. Experimental Setup

Fusion cross-sections for $^{x}C + ^{12}C$ were taken from measurement done by Argonne National Laboratory (ANL) group using active target approach with MUSIC detector [3]. The active target technique is particularly useful for study of low intensity rare ion beams at near barrier energies. Our group had also developed an active target detector known as MUSIC@Indiana [4]. Fusion measurement of $^{39,41,45,47}K$ and $^{36,44}Ar$ with ^{16}O target were performed at National Superconducting Cyclotron Laboratory at Michigan State University using ReA3 facility. Beam incident on target was identified particle-by-particle using ΔE-TOF measurement, here ΔE was measured using axial gas field detector RIPD and time of flight (TOF) was measured using two Microchannel plate detectors (MCP). The target used was as mixed target of ^{28}Si and ^{16}O. Evaporation residues produced by both ^{28}Si and ^{16}O were distinguished from scatter beam using E-TOF approach, in which evaporation residue energy is measured using annular Si detector whereas, TOF was measured between MCP and Si detectors.

3. Results and Discussions

Average fusion cross-sections above barrier energies of $^{x}C + {}^{12}C$ are compared with static (RMF-SP) and dynamic models (TDHF), It has been observed that models failed to explain the observed increase in the experimental fusion cross-sections for neutron-rich nuclei. The failure of TDHF calculations hinted that neutron dynamics included in model need to be revisited and more fusion measurements of neutron rich nuclei is necessary.

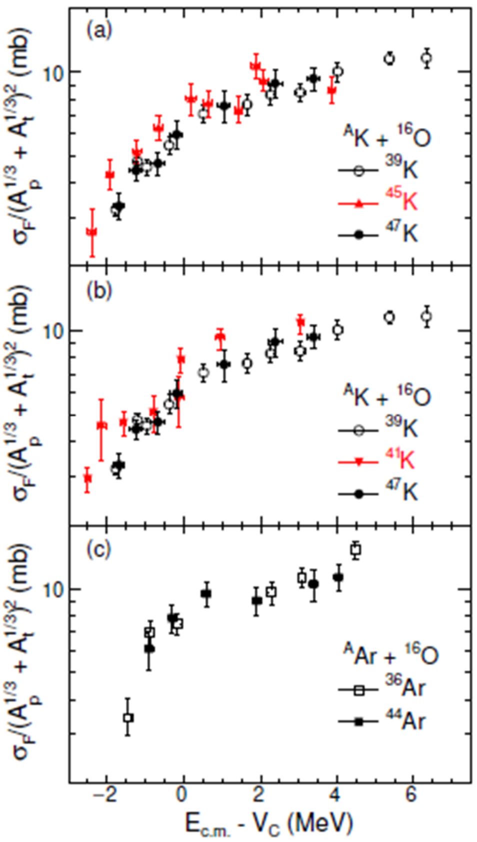

Fig. 1 Comparison of reduced fusion cross-sections for different beams on 16O target under investigation.

Figure 1 shows the reduced fusion excitation function for different isotopes of K and Ar beams on ^{16}O target. It has been observed that reduced fusion cross-sections for shell closed beam nuclei (^{39}K and ^{47}K) are lower than non-shell closed nuclei (^{45}K and ^{41}K). In case of Ar since both nuclei under study are non-shell closed so it behaves exactly same in reduced scale. This indicates the effect of shell closure on fusion cross-sections and hence on fusion dynamics. Experimental cross-sections are compared with theoretical predictions from Sao Paulo model using density distributions obtained from systematics and from Dirac Hartee Bogoliubov (DHB) calculations. Sao Paulo model with DHB densities explained the fusion excitation function of non-shell closed nuclei whereas, over-predict the cross-sections for shell closed nuclei.

Acknowledgments

We are thankful to staff at NSCL for providing high quality beams, without which this measurement was not possible. The work is supported by U.S. Department of Energy under Grant No. DE-FG02-88ER-40404 (Indiana University).

References

[1] R. T. deSouza et al. Physics Letter B **814**, 136115 (2021).
[2] Varinderjit Singh et al. Phys. Rev. C (Letter) Accpted (2021).
[3] P.F.F. Carnelli et al. Nucl. Instrum. Methods Phys. Res. Sect. A **799**, 197 (2015).
[4] J.E. Johnstone et al. Nucl. Inst. And Methods in Phys. Research A **1014**, 165697 (2021).