Exploring the Competitive Behaviour in Nuclear Reactions Around Coulomb Barrier

Prashant Sharma* and Tapan Nandi†
Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA

Introduction

In heavy ion reactions around the barrier energies, there is an interplay between different nuclear reactions e.g. inelastic, transfer, fusion etc. due to strong coupling among them [1]. Transfer and fusion compare well around the Coulomb barrier (CB), whereas fusion dominates over transfer above the CB [2]. A series of experiments initiated in our lab showed that such studies could be efficiently performed by combining atomic and nuclear techniques [3]. A wide range of beam energies and target combinations have enabled us to discover important phenomena viz. formation of fully stripped ions produced from nuclear reactions and multi-electron capture by bare projectile-like fragment (PLF)/ target-like fragment (TLF) ions from electrons left by projectile ions/target atoms. Further, the technique enables us to study various nuclear phenomena, which can't be studied efficiently with the conventional nuclear techniques. This report focusses on revealing a fact that multi cluster transfer and fusion reactions are indeed competitive around the barrier through atomic techniques.

Experimental Setup

Experiments were performed in a wide range of beam energies in the General Purpose Scattering Chamber, IUAC, New Delhi. Well-collimated ion beam of ^{56}Fe at 40-136 MeV, was bombarded on natural carbon of thickness 80 μg/cm^2, which was placed at 45° to the beam axis. The detailed experimental procedure is described in another report in this proceedings.

*Electronic address: prashant@iuac.res.in
†Electronic address: nanditapan@gmail.com

Results and Disscussion

X-ray energy spectra around CB observed in ^{56}Fe on ^{12}C reaction are shown in FIG.1. Besides the projectile x-ray peak, certain additional structures are also observed, as given in TABLE I. A detailed analysis reveals that these structures belong to α, 2α and Li capture products. Charge states of PLF ions were measured using x-ray technique [4], which suggests the huge ionization during nuclear reactions. A clear justification for this unusual ionization is reported elsewhere [3].

TABLE I: Observed X-ray lines, corresponding PLF ions with their charge states and probable reaction channel for Fe beam on C target at around the barrier energies

Beam Energy	X-ray line (keV)	PLF ions	Probable Reaction
116 MeV	7.61	He-like Ni	^{12}C(^{56}Fe,^{60}Ni)
	8.09	H-like Ni	^{12}C(^{56}Fe,^{60}Ni)
	8.88	He-like Zn	^{12}C(^{56}Fe,^{64}Zn)
	9.35	H-like Zn	^{12}C(^{56}Fe,^{64}Zn)
120 MeV	7.62	He-like Ni	^{12}C(^{56}Fe,^{60}Ni)
	8.09	H-like Ni	^{12}C(^{56}Fe,^{60}Ni)
	8.94	H-like Zn	^{12}C(^{56}Fe,^{64}Zn)
	9.36	He-like Ga	^{12}C(^{56}Fe,^{67}Ga)
	9.79	He-like Ge	^{12}C(^{56}Fe,^{68}Ge)
126 MeV	7.65	He-like Ni	^{12}C(^{56}Fe,^{60}Ni)
	8.12	H-like Ni	^{12}C(^{56}Fe,^{60}Ni)
	8.95	H-like Zn	^{12}C(^{56}Fe,^{64}Zn)
	9.37	H-like Ga	^{12}C(^{56}Fe,^{67}Ga)
	9.81	H-like Ge	^{12}C(^{56}Fe,^{68}Ge)

The CB is calculated to be 121.36 MeV for the present system [5]. Spectra given in FIG.1 are clubbed together in FIG.2. It clearly exhibits that below CB 2α pickup products dominate over fusion products, whereas above CB fusion products are more prominent than the 2α products [2].

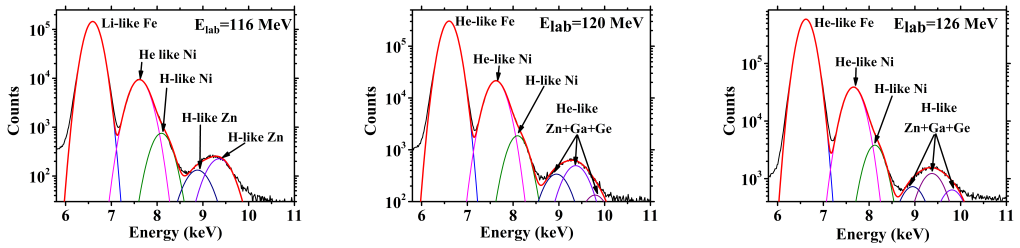

FIG. 1: Different x-ray spectra observed around the Coulomb barrier (121.36 MeV [5]) for Fe beam on C target

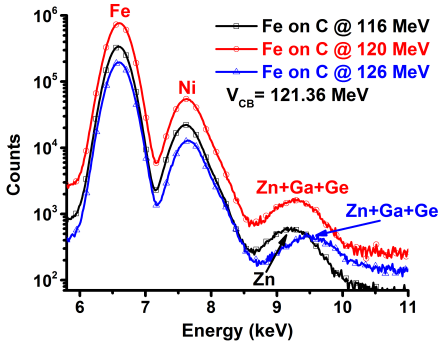

FIG. 2: Competitive behaviour of different nuclear reactions near CB

Conclusion

A clear picture of competitive behaviour between different nuclear reactions around the CB has been observed using atomic techniques. Further, other features e.g. higher charge state of PLF ions than the projectile ions, nuclear reaction products in sub-barrier regime etc. are also observed in the spectra. In near future, similar interdisciplinary experiments will be carried out for heavier system to check any limitation of the technique.

Acknowledgements

We would like to acknowledge the cooperation and support received from the Pelletron accelerator staff and all colleagues of Atomic physics group, IUAC, New Delhi. Prashant Sharma is thankful to UGC, India for providing the fellowship as financial support to carry out this work.

References

[1] A. C. Xenoulis, in Clust. Phenom. Atoms Nucl. SE - 64, edited by M. Brenner, T. Lnnroth, and F. B. Malik (Springer Berlin Heidelberg, 1992), pp. 540 - 550.
[2] L. Corradi, J. Phys. Conf. Ser. 282, 012005 (2011).
[3] T. Nandi, P. Sharma et.al., IUAC Annual Report 5.4.1, (2014).
[4] J. P. Santos, et.al. Phys. Rev. A 82, 062516 (2010)
[5] R. J. Charity et.al., Nucl. Phys. A 483, 371 (1988)