The FRENA facility and sub-Coulomb transfer reactions

Chinmay Basu
Saha Institute of Nuclear Physics, 1/AF Bidhan Nagar, Kolkata 700064, INDIA
** email: chinmay.basu@saha.ac.in*

FRENA is an upcoming low energy (0.2-3 MV) high current accelerator facility that can deliver proton, alpha and heavy ion beams. A dedicated ready to use beamline will be available for capture reaction measurements relevant to the astrophysical scenario. Another beamline with a 1m scattering chamber is being setup to study mainly the charged particle channels. Such reactions may be elastic resonance scattering, charged particle emitting reactions in the CNO cycle and Carbon burning and deep sub-barrier fission reactions. However one of the most interesting reaction is the sub-Coulomb transfer reaction. This reaction helps in R-matrix extrapolation to determine capture cross-section at the Gamow energy.

1. Introduction

FRENA (Facility for Research in low Energy Nuclear Astrophysics) is being setup at the Saha Institute of Nuclear Physics, Kolkata. The details about the accelerator can be found in the literature. The facility will be ready to deliver beams from early next year. Proton, Alpha and Heavy ion beams will be obtained with high currents ranging from a few tens to hundreds of microamperes. There are four beamlines possible after the second and final switching magnet. Out of these, one beamline is available for cross-section measurements of capture reactions. In another port a 1m scattering chamber is being developed for detection of charged particle channels in astrophysical reactions such as in $^{12}C+^{12}C$ and in CNO cycle reactions . Apart from direct measurements the low energy accelerator is most suitable for indirect measurements in astrophysics, particularly by the Asymptotic Normalization Constant (ANC) method. This method uses the transfer reaction to determine the ANC which in turn can determine the low energy capture cross-section. This technique is model dependent if the transfer reaction is performed at higher energy. At sub-Coulomb energies the model dependence in the extracted ANC can be largely avoided as the dependence on the nuclear potentials become very small A facility like FRENA therefore opens up a great opportunity to pursue the ANC technique and determine the astrophysical cross-sections at the Gamow energy.

In this presentation a brief description of the experimental prospects with FRENA will be given with emphasis to charged particle channels. In particular the sub-Coulomb transfer reactions will be discussed with reference to experiments carried out at existing higher energy accelerator facilities.

2. FRENA user's scope

FRENA is a low energy (0.2-3MV) high current accelerator facility. The details of the machine has been published in the literature and also discussed previously in several meetings, workshops and conferences. The machine is expected to deliver beam from early next year and so in this presentation I would highlight the scope in the facility from the user's point of view.

The layout of FRENA can be seen in the following figure. In the high energy section after

Fig. 1 FRENA accelerator hall

the first switching magnet one beamline is ready to be used with pulsed proton beam. There are two other ports where proton and unanalyzed (mixed charge states) alpha and heavy-ion beams can be utilized. After the 90 degree analyzing magnet the beam can be also be taken out straight or the analyzed beam bends and passes the second switching magnet. After this switching magnet one beamline is ready and dedicated for the capture cross-section measurements. Another port at 15 degree is being setup for a 1 m scattering chamber. The chamber has two movable arms each with a three plate structure for mounting the detectors. Detailed features of the stainless steel chamber will be discussed in the presentation. Another port of the switching magnet at 30 degrees will be developed for (Rutherford backscattering) RBS studies.

3. Sub-Coulomb transfer reaction

Direct measurement of charged particle channels such as for $^{12}C+^{12}C$ [2], $^{12}C+^{13}C$ reaction and $^{19}F(p,\alpha)$ [3] reaction is of utmost interest in nuclear astrophysics. The latter reaction also poses the question of reaction mechanism i.e whether the reaction proceeds through a direct process or not. However all direct measurements are extremely challenging.

The Indirect method in nuclear astrophysics on the other hand is very beneficial to study capture reactions at the Gamow energy. The capture cross-sections are very small (~pb-nb) and their direct measurements are often very difficult. R-matrix extrapolation is the only way to obtain the cross-section. The R-matrix extrapolation depends sensitively on the ANC of the bound states of the nucleus of interest. As an example, the $^{12}C(\alpha,\gamma)$ cross-section needs to be determined at 300 keV and its direct measurement is very difficult. The R-matrix extrapolation of this cross-section is dependent on the ANC of the 6.92 and 7.12 MeV states of ^{16}O.

The ANC can be determined from $^{12}C(^{6/7}Li,d/t)$ ^{16}O alpha transfer reactions. Several measurements at above barrier energies [4,5 & references therein] have been carried out in recent times but the extracted results suffer from a reasonable discrepancy from each other. The main source of the uncertainty is the nuclear potentials that enter in the direct reaction model calculations required in this method.

On the other hand if the transfer reaction is performed at sub-Coulomb energies then this model dependence in the extracted ANC can be avoided. There are so far very few of such sub-Coulomb transfer measurements [6,7] and studies [8] only for $^{12}C(\alpha,\gamma)$ and $^{13}C(\alpha,n)$ reaction [9]. The angular distribution measurements need to be carried out at backward angles only where nuclear processes will be dominant. Recently preparation of deuterated polyethylene targets have been taken up and this will enable proton and neutron capture reaction measurement using proton and neutron transfer reactions.

Simple two detector telescopes are sufficient for such measurements in the scattering chamber. The thin targets are not enough heated by the high current beam and cooling arrangements are not required. In brief in the low energy domain sub-Coulomb transfer measurements will play a vital role in the forthcoming experiments with FRENA facility..

Acknowledgments

I acknowledge the cooperation of my group members.

References

[1] N.C. Podaru, A Gottdang, D.J.W Mous and FRENA group, Nucl. Instr. Methods B **273** (2012) 231.
[2] T.Spillane et al, Phys. Rev. Letts. **98** (2007) 122501
[3] H. Herndl et al, Phys. Rev. C **44** (199) R952.
[4] S.Adhikari, C.Basu, I.J. Thompson et al, Phys. Rev C **89** (2014) 044618
[5] S.Adhikari, C. Basu, P. Suhathan et al, Jour. Phys. G Nucl. Part. Phys. **44** (2016) 015102
[6] C. Brune et al, Phys. Rev. Lett. B **83** (1999) 4025
[7] M.L. Avila et al, Phys. Rev. Lett. **114** (2015) 071101
[8] A. Mondal, S. Adhikari, C. Basu, Phys. Lett. B **772** (2017) 216
[9] E.D. Johnson et al, Phys. Rev. Lett. **97** (2006) 192701