FRENA – A low energy, high current accelerator facility for research in Nuclear Astrophysics at SINP, Kolkata

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Introduction

Over the last couple of decades, following the seminal work of Burbidge, Burbidge, Fowler and Hoyle in 1957 [1], Nuclear Astrophysics has evolved as a vibrant field studying the fundamental questions related to the synthesis of elements through various nuclear processes occurring at widely different astrophysical scenarios [2]. The synergy of the rates of astrophysically relevant nuclear reactions and the astronomical observations is of current interest in Nuclear Astrophysics in understanding the evolutionary processes in the universe.

The study of nuclear astrophysics involves precise measurement of reaction rates with very low probabilities or cross sections at astrophysical energies. The effort requires intense, stable beams of different species from the accelerators with energies ranging from several keV to tens of MeV in order to cover the various astrophysical conditions. Each reaction of relevance represents a case of its own and requires specialized experimental tools (like accelerators, detectors, target, etc.) for its investigation. The experiments also required to adopt novel direct or indirect techniques to extract the precise data.

With the aim of developing a facility for research in experimental nuclear astrophysics, Saha Institute of Nuclear Physics, Kolkata, INDIA proposed the facility, FRENA

The Accelerator

The acronym FRENA stands for Facility for Research in Experimental Nuclear Astrophysics. The proposed facility, presently under the process of installation at the Bidhannagar Campus of SINP, is built around a 3 MV Tandetron (Tandem Accelerator) with a lowest terminal voltage of 200 kV. This accelerator has primarily been procured from High Voltage Engineering, The Netherlands, and is being assembled at the site for FRENA. The machine is capable of delivering very high beam currents required for experiments studying the reactions of astrophysical interest.

The accelerator uses a Cockroft-Walton type voltage generator with all solid-state, high voltage power supply that can provide terminal voltages in the range of 0.2-3.0 MV [3]. The standard terminal voltage setting resolution is $3x10^{-5}$ times the maximum terminal voltage, i.e. it is about 100 V at 3MV. This implies that the energies for ions with charge state 2^+ can be varied in steps of ~300 eV. Terminal voltage stability is expected to be ±25 V and ±300 V at lowest and highest terminal voltages, respectively. The machine uses three different ion-sources to provide light-ion beams like ^{1}H, ^{3}He and ^{4}He as well as all heavy-ions up to ^{197}Au. The light ion source consists of a dual source injector with a Multi-cusp ion source for ^{1}H and another Multi-cusp source for ^{3}He and ^{4}He. A facility for chopper-buncher arrangement is also included with the light ion channel to obtain pulsed ^{1}H, ^{3}He and ^{4}He beams. The heavy ions are provided by a SNICS type sputter ion source. The negative sputter multi-target (50 target carrousel) heavy ion source has been specially configured in view of the long-duration measurements, essential in the study of reactions with low cross-sections that necessitate repeated change of ion-source targets. One of the strong features of Tandetron-based accelerators is the stable operation at low energies, which results from the all-solid-state power supply with a very fast controllable feedback-loop.

The Scope

The system is provided with two beam lines at present. One for the nuclear astrophysics applications after the second high energy switching magnet and the other is a beam line for pulsed beam application coming after the first high energy switching magnet before the analyzing magnet. No pulsed heavy ion is available at this moment. Typical values of beam currents that will available with the machine is given in Table 1.

Table 1: Typical beam currents

Beam (Ch. State)	Expected Current at 3MV (eμA)	Expected Current at 200kV (eμA)
H (1+)	350	50
3,4He (2+/1+)	50	6
12C (3+/1+)	30	12
58Ni (3+)	~3	• Measured at -15 deg. Port after the first switching magnet
63Cu (3+)	~4	
197Au (2+)	~16	

Physics Plans

The energy domain of FRENA will be most suitable to study the heavy ion fusion reactions in nuclear astrophysics [3]. Hence, the ^{12}C +^{12}C reaction, the rate of the reaction is one of the key quantities needed to understand the evolution of massive stars (> 8 Solar Mass) and the nucleosynthesis of heavy elements, may be the first one which will be attempted. The proton capture reaction $^{14}N(p,\gamma)^{15}O$, the slowest reaction of the CNO cycle, regulates the power generated by the cycle and thus influences the structure and evolution of every star at different stages of their life. Studying this reaction at FRENA is a part of the immediate physics goal. Studying the sub-coulomb transfer reactions as an indirect technique to extract the astrophysically relevant quantities, especially for reactions like alpha capture reaction $^{12}C(\alpha,\gamma)$, will be pursued as some of the first experiments at FRENA.

The salient features of the accelerator, its capability as a tool for nuclear astrophysics research and the immediate experimental plans will be highlighted in the presentation.

References

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