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STATUS OF THE CANREB EBIS AT TRIUMF

B. E. Schultz†, F. Ames, S. B. Beale, M. Cavenaile, C. R. J. Charles
TRIUMF, Vancouver, Canada V6T 2A3

Abstract

The CANadian Rare isotope facility with Electron Beam ion source (CANREB) is an essential part of the Advanced Rare IsotopE Laboratory (ARIEL) presently under construction at TRIUMF. CANREB can accept stable or rare isotope beams from a variety of ion sources, delivering high purity beams of highly charged ions (HCI) to experiments. The injected beams are bunched and cooled using a radiofrequency quadrupole (RFQ) cooler-buncher, and energy adjusted using a pulsed drift tube for injection into an electron beam ion source (EBIS) charge breeder. The EBIS was designed for a maximum electron beam current of 500 mA at a maximum magnetic field of 6 T. The EBIS can accept ion beam energies up to 14 keV and HCI with $3 < A/q < 7$ can be charge bred and extracted. The HCIs are separated using a Nier-type spectrometer before being transported to the linac for post acceleration. The status of the CANREB EBIS and recent results will be presented.

INTRODUCTION

TRIUMF houses a cyclotron which can produce proton beams at energies up to 520 MeV and currents up to 120 μA (> 300 μA total for all beamlines). For production of rare isotope beams (RIB), protons with energy 480 MeV (and currents up to 100 μA) impinge on targets comprised of U, Ta, Si, Th, Nb, or C [1]. Reaction products are formed through fission and spalation reactions and ionized using surface, laser, or plasma discharge ion sources. Ions are extracted at energies up to 60 keV and can be transported directly to low energy experiments in the Isotope Separator and ACcelerator (ISAC) facility. Ions can also be transported to high energy experiments (up to 15 MeV/nucleon for low A/q) following post-acceleration through a multi-stage (room temperature and superconducting) linac. The linac has an energy acceptance of 2.04 keV/nucleon, limiting the mass-to-charge ratio to $A/q = 30$ for 60 keV. Post-acceleration of heavier ions requires charge breeding to $3 < A/q < 7$. Currently, highly charged ions (HCI) are created using an electron cyclotron resonance ion source (ECRIS) installed in ISAC [2]. The ECRIS is limited to efficiencies of a few percent, and also generates high background currents due to high residual gas pressure and plasma chamber sputtering. The resulting isobaric currents can be several orders of magnitude more intense than the species of interest. The maximum achievable charge state from the ECRIS is also limited, and secondary stripping in the linac is often required to reach the necessary energy which further limits the efficiency.

The Advanced Rare IsotopE Laboratory (ARIEL) project is currently under construction at TRIUMF. In addition to adding two new target stations for RIB production, ARIEL also includes the CANadian Rare isotope facility with Electron Beam ion source (CANREB) for charge breeding of ions. CANREB utilizes an electron beam ion source (EBIS) to generate HCI. The EBIS is designed for ultrahigh vacuum operation, which greatly reduces the background contamination relative to the ECRIS. The EBIS can also reach higher charges states, mitigating the need for a second stripping and permitting the delivery of clean and intense post-accelerated beams to ISAC.

CANREB OVERVIEW

CANREB is located in the ARIEL building adjacent to ISAC (Fig. 1). The lower level of the ARIEL building contains the future mass separator room, which houses the CANREB high resolution separator (HRS). The HRS has a dual magnetic dipole which is designed to reach resolving powers up to 20000 [3]. The HRS can accept beam from the future ARIEL target stations, which is then transported upstairs through a vertical beamlime. If additional mass separation is not required, the HRS can be bypassed. The HRS is currently being commissioned off-line. The mass separator room also contains the ARIEL test ion source (TIS) [4], a small surface source used for stable beam tests in CANREB.

The CANREB charge breeding systems are located on the ground floor of the ARIEL building. Stable ion beams can be injected from the TIS or from the off-line ion source (OLIS) in ISAC. RIB can currently be injected from the ISAC target stations and from ARIEL in the future. Ions can be injected at energies up to 60 keV into the radiofrequency quadrupole (RFQ) cooler-buncher [5] with intensities up to a few 100 pA. The ions are confined using a combination of DC electric and RF fields ($f_{RF} = 3 - 6$ MHz) for up to 10 ms (at a nominal rep rate of 100 Hz). A helium buffer gas ($P \approx 30$ mTorr) cools the trapped ions. The extracted ions have a nominal FWHM width of ≈ 1 μs. The extracted ions must be reduced in energy for coupling into the charge breeder, which is accomplished using a pulsed drift tube (PDT). The PDT is rapidly switched between high voltage and ground using a push-pull Behlke switch (fall time < 500 ns).

The EBIS was designed and constructed at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany [6]. The system is designed to accept ions with energies up to 14 keV (set by the desired A/q and the energy acceptance of the linac) and intensities up to $\sim 10^7$ particles per bunch at 100 Hz. The ions are confined electrostatically in the center of a split-bore, semi-Helmholtz superconducting (4 K) magnet with a maximum field strength of 6 T. A barium dispenser cathode generates an electron beam with an energy

†bschultz@triumf.ca

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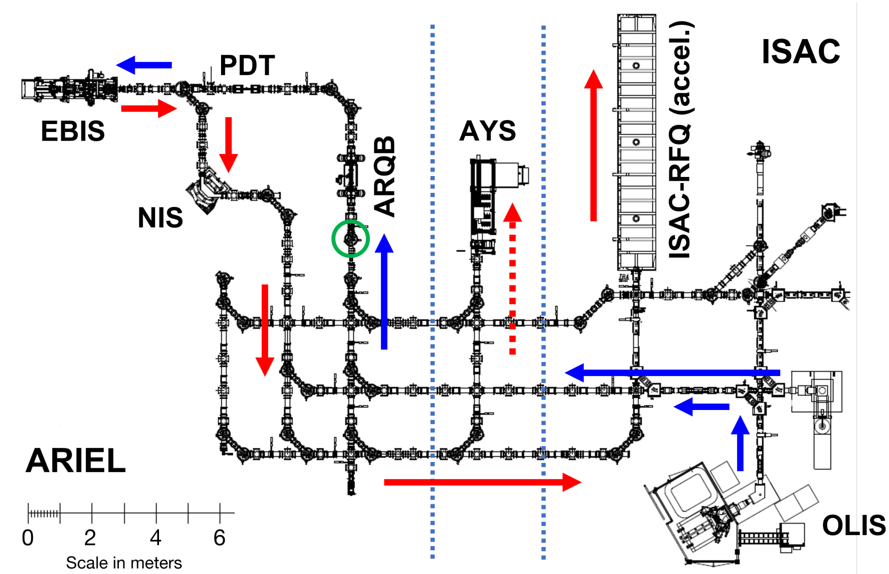

Figure 1: Layout of CANREB charge breeding systems. See text for acronym definitions. Blue arrows indicate path of beam injected into CANREB, either from OLIS or the ISAC target stations. Charge bred RIB from the EBIS can either be sent to the AYS for yield measurement (dashed red arrow) or into the ISAC linac for post-acceleration (solid red arrows). In the future, beam from the new ARIEL target stations can be injected into CANREB (green circle) and charge bred in the EBIS.

and current of up to 15 keV and 500 mA, respectively. The electron beam is compressed through the trapping region by the magnetic field before being deposited onto an electron collector. The drift tubes in the trapping region are cooled with the magnet to ≈ 4 K to act as a getter to reduce the residual gas pressure in the charge breeding region. Trapped ions are charge bred for up to 10 ms and are then extracted and transported through a Nier-type spectrometer (NIS) for charge state separation ($m/dm \approx 300$).

EBIS COMMISSIONING AND STATUS

For EBIS commissioning the ion beam energy—which is set by the high voltage (HV) bias of the central drift tubes—was limited to a maximum of 7 keV. In the presence of a strong magnetic field, higher voltages would lead to a persistent HV discharge, creating negative vacuum effects and voltage instabilities that rendered the system inoperable. The discharge was only present with the magnetic field turned on, which required the maximum field strength to be limited to 1 T. Attempts to address this issue following high voltage failures in 2019 and 2021 were only partially successful; investigations (and simulations [7]) are underway to try and solve the problem. In addition to voltage limitations, the electron gun current was limited to 40 mA.

The EBIS was commissioned using a number of ion beams. The TIS provided ^{85}Rb and ^{133}Cs beams at energies up to 30 keV. A variety of alkali (Rb, Cs) and noble gas beams (Kr, Ar) were injected from OLIS. Radioactive beams from an ISAC target station were also charge bred and successfully post-accelerated to a high energy experiment for tests [8].

An A/q spectrum of charge bred ^{85}Rb from OLIS is plotted in Fig. 2 (top), measured prior to the latest HV failure. The black and red spectra were measured with the Rb injected into the EBIS and blocked, respectively. The EBIS was operating with $B = 1$ T and an electron beam energy/current of 4.3 keV/27 mA. The ion energy was 6.3 keVxq and the charge breeding time was 8 ms. The spectra were recorded by varying the magnetic field of the NIS and recording the ion beam current on a downstream Faraday cup. The A/q-axis has been truncated to show the region of interest for post-acceleration. Figure 2 (bottom) shows the resulting charge state distribution (CSD) and relative abundances of the various charge states. In the peak of the CSD (roughly Rb 11+) the charge breeding efficiency was ≈ 2% with an injected beam current of 200 pA. For comparison, the CSD for an 8 ms charge breeding time was estimated using CBSIM [9]. The electron beam current density was adjusted to match the peak of the distribution, giving a value of 50 A/cm^2. For these electron beam parameters, the Herrmann radius was estimated to be 112 μm, giving a current density of ≈ 70 A/cm^2 which is consistent with CBSIM. The measured CSD is much broader than that generated by CBSIM, with lower and higher charge states. This could be caused by poor overlap of the ion cloud with the electron beam and/or the trap not being fully emptied after each charge breeding cycle.

The EBIS was recently brought back to an operational state following the latest HV failure. Figure 3 shows A/q

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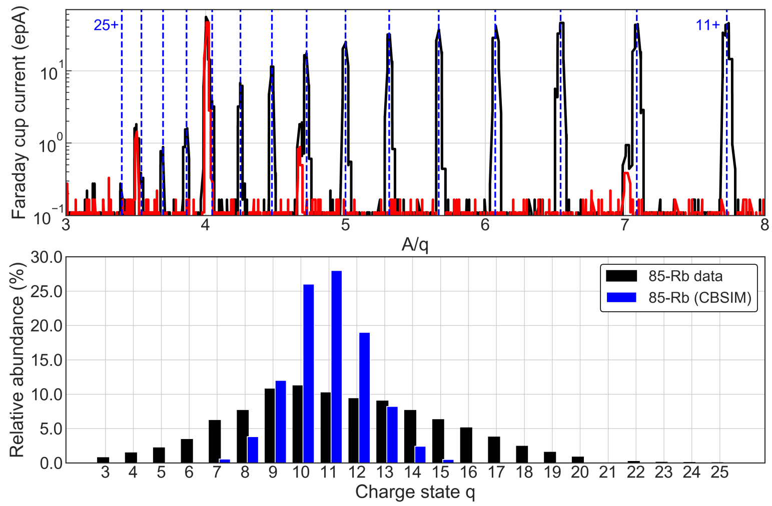

Figure 2: [85]Rb charge bred in the EBIS. Electron beam energy = 4.3 keV, electron beam current = 27 mA, magnetic field = 1 T, charge breeding time = 8 ms, and ion energy = 6.3 keVxq. (Top) A/q spectra with the Rb beam injected (black) and blocked (red). Blue dashed lines indicate position of Rb charge states from 11–25+. (Bottom) Charge state distribution and relative charge state abundances for measured data (black) and simulated data (blue).

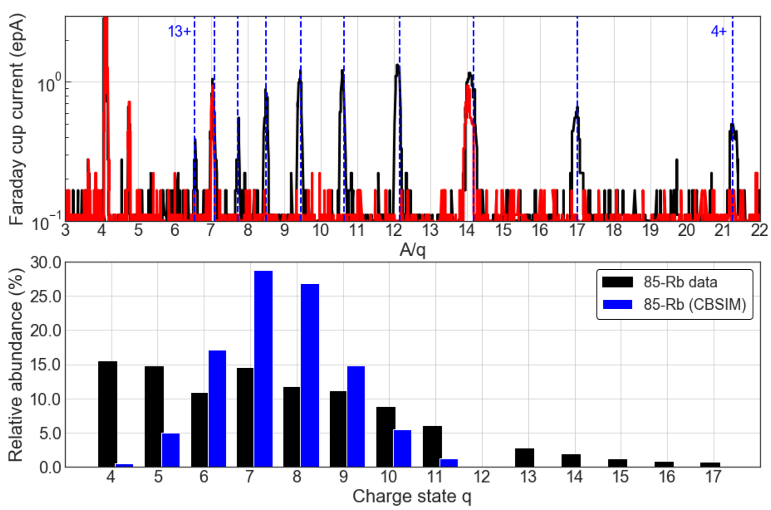

Figure 3: [85]Rb charge bred in the EBIS. Electron beam energy = 4.3 keV, electron beam current = 17 mA, magnetic field = 1 T, charge breeding time = 4 ms, and ion energy = 5.3 keVxq. (Top) A/q spectra with the Rb beam injected (black) and blocked (red). Blue dashed lines indicate position of Rb charge states from 4–13+. (Bottom) Charge state distribution and relative charge state abundances for measured data (black) and simulated data (blue).

spectra (top) and charge state distribution (bottom). The EBIS was operating with $B = 1$ T and an electron beam energy/current of 4.3 keV/17 mA. The ion energy was 5.3 keVxq and the charge breeding time was 4 ms. In the peak of the distribution (roughly Rb 7+) the charge breeding efficiency was < 0.1%. Similar to the data from 2021, the CSD is broad compared to that predicted by CBSIM, which could again indicate issues with ion trapping. The electron beam current density in CBSIM was 32 A/cm^2, compared to 44 A/cm^2 as estimated from theory.

CONCLUSION

CANREB has been built to charge breed stable and rare isotope beams using an EBIS for post-acceleration to high energy experiments in ISAC. CANREB systems have been commissioned, and the RFQ cooler-buncher, PDT, and NIS are all operating to specifications. A number of ion species have been charge bred in the EBIS for times up to 8 ms, achieving single charge state efficiencies up to ≈ 2% in the peak of the charge state distributions.

EBIS performance during commissioning was limited due to high voltage stability issues relating to discharge through

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the drift tube bias. The discharge was strongly correlated to the presence of the magnetic field. As a result, the ion beam energy was limited to < 7 keV x q at a maximum magnetic field of 1 T. These parameters were sufficient for commissioning, but will not allow the system to be operated within the full range required for beam delivery at TRIUMF (6–14 keV). Attempts to resolve this issue have up-to-now been largely unsuccessful, and efforts are underway to try and fix the problem. Once the high voltage can be operated to specification, efforts will focus on improving EBIS efficiency and overall performance.

REFERENCES

[1] *ISAC and ARIEL: The TRIUMF Radioactive Beam Facilities and the Scientific Program*, J. Dilling, R. Krücken and L. Merminga Ed. Dordrecht, Netherlands: Springer, 2014.

[2] F. Ames, R. Baartman, P. Bricault and K. Jayamanna, *Hyperfine Interact.*, vol. 225, pp. 63–67, 2014.

[3] M. Marchetto *et al.*, *Nucl. Instrum. Methods Phys. Res. B*, vol. 463, pp. 227–231, 2020.

[4] S. Saminathan, F. Ames, R. Baartman, M. Marchetto, O. Lailey and A. Mahon, *Rev. Sci. Instrum.*, vol. 90, pp. 123302, 2019.

[5] B. R. Barquest, J. C. Bale, J. Dilling, G. Gwinner, R. Kanungo, R. Krücken and M. R. Pearson, *Nucl. Instrum. Methods Phys. Res. B*, vol. 376, pp. 207–210, 2016.

[6] M. A. Blessenohl *et al.*, *Rev. Sci. Instrum.*, vol. 89, pp. 052401, 2018.

[7] C. R. J. Charles *et al.*, "Simulations of the CANREB EBIS: Where Might the Issue(s) Be?", presented at the 14th Int. Symp. of EBIS/T, Whistler, Canada, June 2022, this conference.

[8] B. E. Schultz, C. R. J. Charles, M. Cavenaile, R. Kanungo, F. Ames and O. Kester, *J. Phys.: Conf. Ser.*, vol. 2244, pp. 012028, 2022.

[9] R. Becker, O. Kester and Th. Stoehlker, *J. Phys.: Conf. Ser.*, vol. 58, pp. 443-446, 2007.