Towards Radioactive Molecular Beams at CANREB

D. Joseph[a,b], C. Charles[a,b,d], C. Andreoiu[b], P. Harford[c], F. Ames[a], B. Schultz[a]

[a] TRIUMF. 4004 Wesbrook Mall, Vancouver BC, V6T 2A3, Canada.
[b] Department of Chemistry, Simon Fraser University. Burnaby BC, V5A 1S6, Canada.
[c] Department of Physics, University of Toronto. Toronto ON, M5S 1A1, Canada.
[d] Department of Earth Sciences, Western University. London ON, N6A 3K7, Canada.

Introduction

CANREB is TRIUMF's flagship facility that creates and delivers beams of highly charged ions (HCI). CANREB includes a cooler-buncher known as the *ARIEL Radiofrequency Quadrupole Cooler-Buncher (ARQB)* to prepare beams for HCI production. However, the ARQB may also be used for ion-gas chemistry to create **rare radioactive molecular (RM)** beams for next-generation BSM physics searches [1].

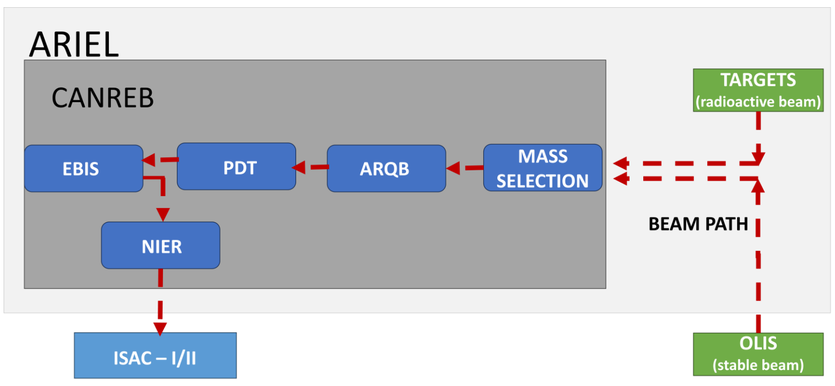

Fig 1: Layout of the CANREB facility and beam path.

Why radioactive molecules?

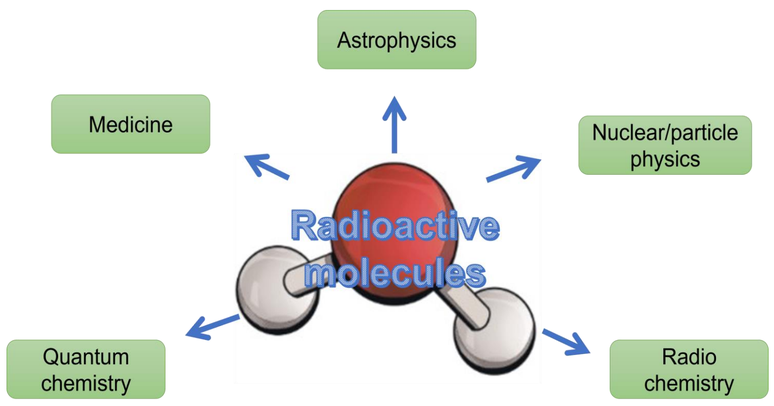

Fig 2: Applications of RM's across different fields.

Molecule creation in cooler-bunchers

The ARQB is a beam cooler and buncher device that is adaptable to produce RMs. Beams entering the ARQB are confined using DC and oscillating RF electric fields. These ions undergo cooling via repeated collisions with a background gas (i.e. helium and/or other). As the ions interact with the gas, they chemically react to form molecules in the same way as the ***RadMol*** group has shown with TRIUMF's TITAN cooler buncher [2].

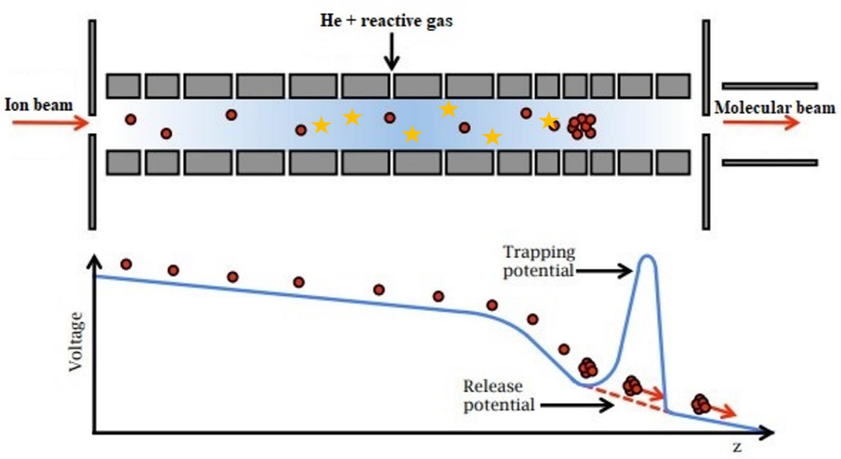

Fig 3: A schematic of the cooler-buncher. Adapted from [3].

How to make molecules at CANREB

- Take beam (radioactive/stable).
- Send beam through ARQB in He & other gas (i.e O_2,SF_6,…).
- Send beam through pulsed-drift tube (PDT) to adjust beam energy for EBIS entry.
- Take beam in and bounce out of EBIS.
- Send through Nier spectrometer for mass selection.
- Count ions using Channel Electron Multiplier.
- Get mass spectra.
- Characterize ability of CANREB to produce, analyze, and deliver rare/exotic molecular beams.

ARQB simulation

An accurate and reliable simulation is essential to understand beam characteristics, ion-gas interactions, conditions inside the ion guide, and optimized use of the ARQB within CANREB (see Figs. 4-5).

Simulation setup

- SIMION version 8.1.1.32.
- **Langevin** and **Hard sphere** collision model.
- Segmented simulation for high resolution:
  - **Entrance** = injection
  - **Body** = cooling
  - **Exit** = bunching/ejection
- Multiple PAs for variable resolution:
  - 0.5 mm/g.u boundaries
  - 0.2 mm/g.u ion pathway
- He pressure profile modeled using MolFlow+ (see Fig. 8).

Discussion and Upcoming tasks

Simulation results show that the conditions in the ARQB are favourable for molecular creation: low energy and low mean free path. Energies of less than 1eV are optimal for ion-molecule reactions [4].

ARQB emittance will be characterize and beam transport down stream will be optimized.

Computational chemistry programs will be used to calculate rate coefficients of different molecular products.

Building of a custom gas mixing system is underway.

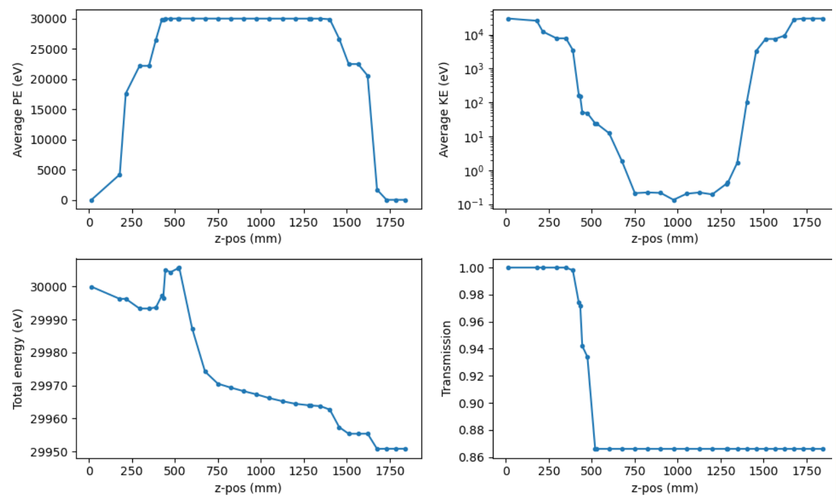

Fig 4: Simulated ion data along the ARQB.

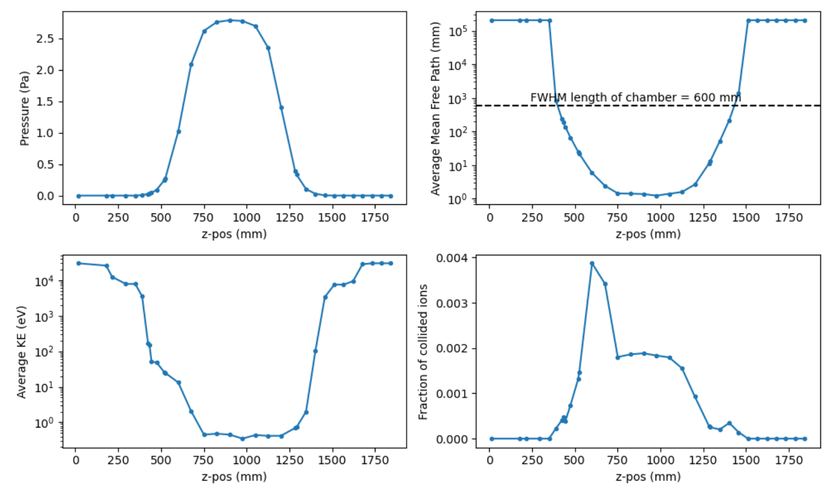

Fig 5: Simulated ion-gas interaction data along the ARQB.

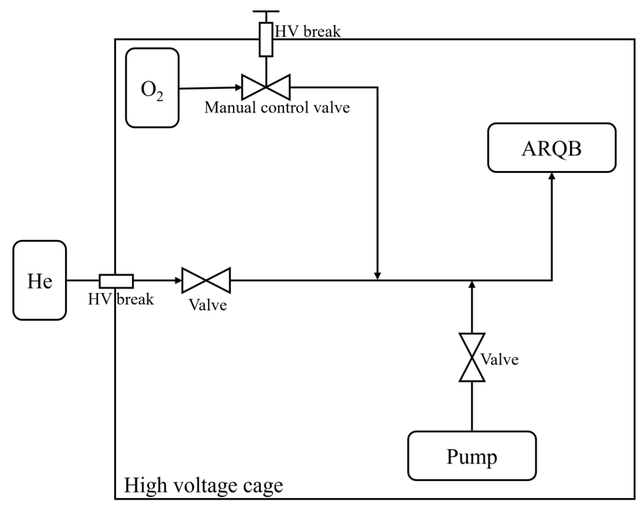

Fig 6: Gas mixing system schematic.

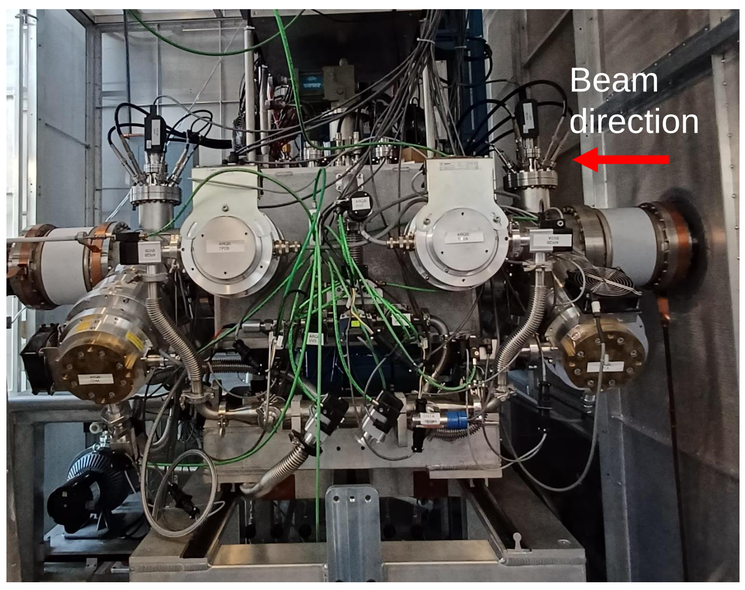

Fig 7: Side view of the ARQB.

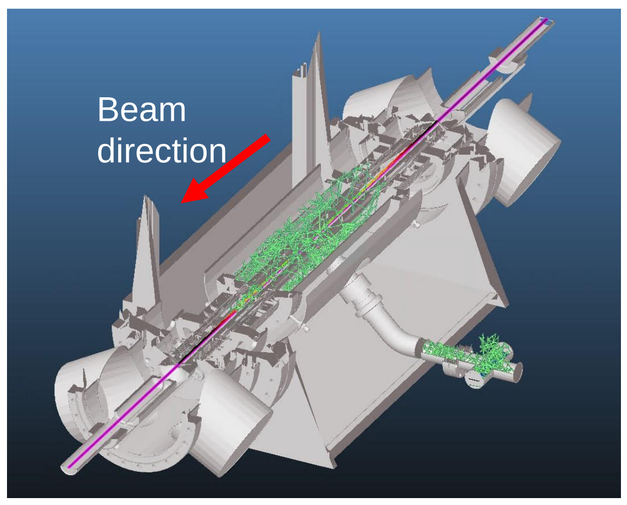

Fig 8: MolFlow+ simulation of the ARQB. In green are the trajectories of the He atoms.

References

[1] C. R. J. Charles, F. Ames, and O. et al. Kester. Production of Radioactive Molecular Ions in Radiofrequency Quadrupole Gas-Reaction Cells. Journal of Physics: Conference Series, 19th International Conference on Ion Sources – ICIS2021, 2244, 2022.

[2] Radioactive molecules for fundamental physics at TRIUMF – Ivana Belosevic (CAP 2023), Univ. of New Brunswick, Halifax, Jun 18-23, 2023, abs. 3975.

[3] K. M. Lynch, 2013, Laser assisted nuclear decay spectroscopy: A new method for studying neutron-deficient francium [Doctoral dissertation, University of Manchester].

[4] Holland, G., & Tanner, S. D. (Eds.). (2001). Plasma source mass spectrometry: The new millennium. The Royal Society of Chemistry.

Discovery, accelerated