FRIB-EDM³: Testing Fundamental Symmetries With Radioactive Molecules In Solids

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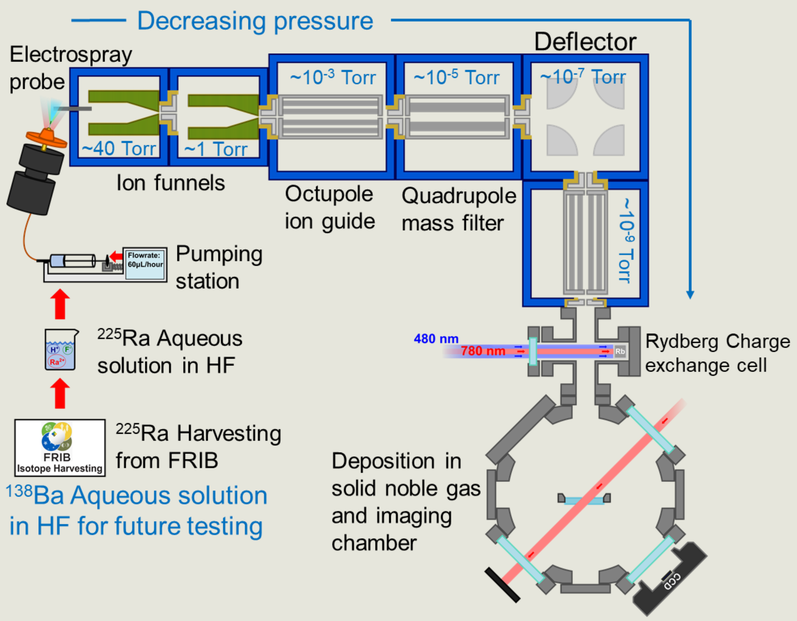
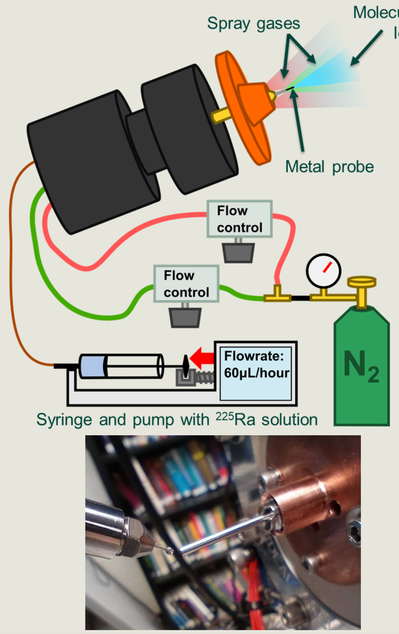
Motivation

The Baryon Asymmetry of the Universe (BAU) is not sufficiently explained by the Standard Model, and requires Beyond Standard Model (BSM) extensions to account for the discrepancy between the observed and predicted BAU [1,2]. New sources of combined charge-parity (CP) symmetry violation could account for this discrepancy [3]. Permanent Electric Dipole Moments (EDMs) are a signature of time-reversal (T) violation and by the CPT theorem, are also a signature of CP violation that can be used to directly search for BSM physics. In hadronic systems, heavily deformed pear-shaped nuclei are expected to have enhanced sensitivity to T violations, resulting in a more pronounced EDM [4]. These pear-shaped nuclei can also be used to form molecules, providing enhanced sensitivity to T violating BSM physics [5]. Further enhancements can be provided by using matrix isolation to trap the molecules in a noble gas matrix, offering high statistics and control of systematic effects [6]. We aim to use rare isotopes to efficiently form polar molecules and embed them in a noble gas matrix, utilizing the FRIB-EDM^3 Instrument. The design of the instrument is split into two parts – a frontend and backend. The frontend will produce molecular ions using electrospray ionization, then concentrate them into an ion beam using electrodynamic ion funnels. The resulting beam will be filtered using a quadrupole mass filter, and separated from line of sight neutrals with an electrostatic bender. Here, we report on the design of the frontend, and discuss the current construction and testing status of it.

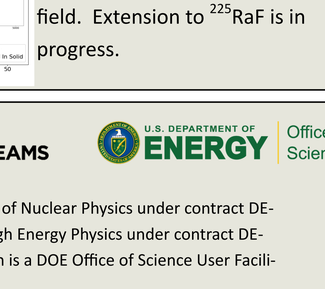
Proposed Experimental Setup



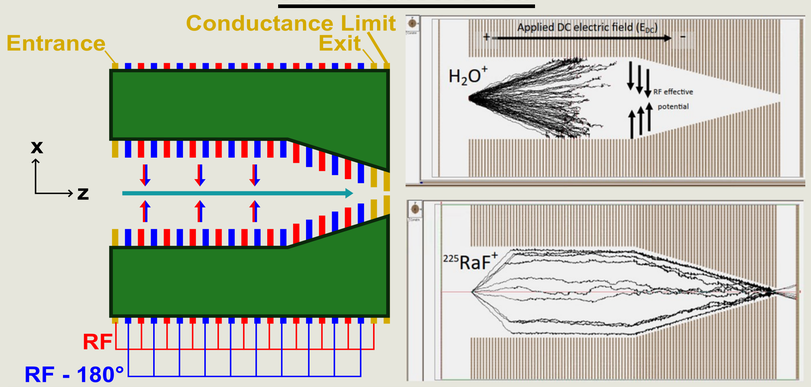
Electrospray Ionization

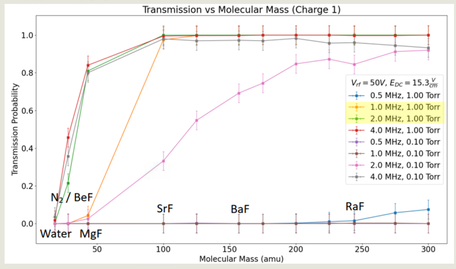


Molecular ions are produced using an electrospray ionization (ESI) source [7]. This ESI source consists of a very narrow metallic capillary that is biased at 1-3 kV. Coupled with microscopic flow rates, this bias produces a plume of charged droplets. Alongside this bias, nitrogen gas is flowed through the probe to shape the spray and aid in droplet desolvation.



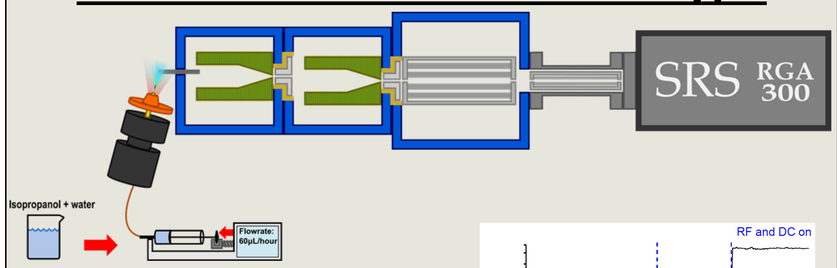
Ion Funnels

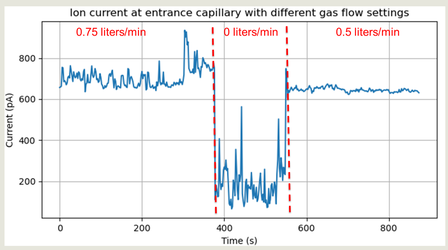


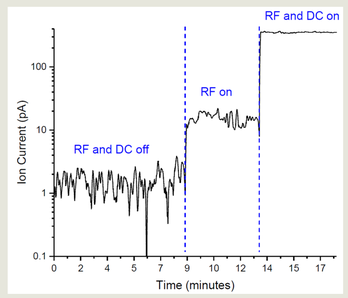


Ion funnels are composed of an array of ring electrodes which are biased with RF and DC. They are used to filter out mass contaminants based on charge-to-mass ratio, by selecting specific operating pressures, DC and RF amplitudes, and RF frequency [8].

FRIB-EDM^3 Frontend Prototype

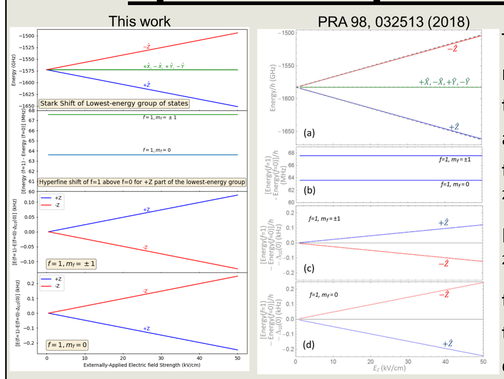


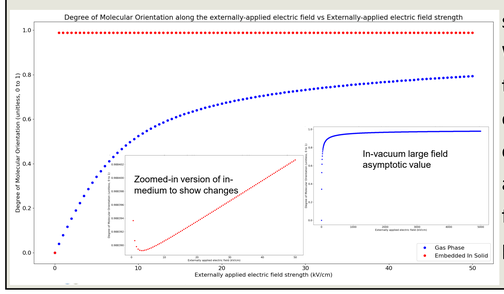




To validate our simulations, we built a prototype of the first few ion filtration stages of the FRIB-EDM^3 instrument's frontend, including all stages up to the quadrupole mass filter. In its place, we have an RGA for obtaining mass spectra. Our ESI source is modified commercial ESI source, and is not reflective of what is intended for the final design. The ion funnels and octupole guide are representative of the final design.

Spectroscopic Calculations





To perform the experiment, we will need a measurement scheme — that is, which states to transition to and from. Thus, we need to know the rotational-hyperfine spectrum of ^{225}RaF embedded in medium. However, the hyperfine structure of ^{225}RaF had not been measured at the start of this work, so we decided to start by reproducing and extending previous calculations on a simpler molecule, ^{138}BaF (see ref. 6). We have successfully reproduced these calculations and have extended them to obtain the degree of molecular orientation in vacuum and in a solid as function of electric field. Extension to ^{225}RaF is in progress.

References

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