Isotope Separator for External Ion Injection into EBIS

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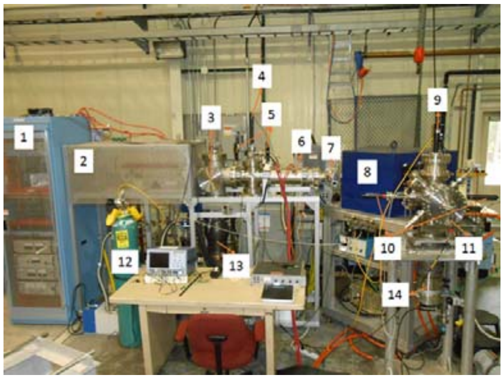
Abstract

An advanced Electron Beam Ion Source (EBIS) was successfully used over the last several years at Brookhaven National Laboratory to supply highly charged ion beams of different elements to the Relativistic Heavy Ion Collider (RHIC) and to the NASA Space Radiation Laboratory (NSRL). It is advantageous to inject isotopically pure beams of singly charged ions into EBIS to enhance RHIC luminosity. For this purpose we are developing an isotope separator based on a 90° double-focusing dipole magnet coupled to a hollow cathode ion source. This source is able to generate 1+ ion beams of different elements for external injection into EBIS with intensity high enough to fully fill the capacity of the EBIS ion trap. A quadruplet of electrostatic quadrupole lenses has been installed in front of the magnet to separate different isotopes in the plane of the magnet output slit. CsI (Tl) scintillator placed near this plane has been used to optimize mass resolution of the separator. The main challenge was to achieve simultaneously both required resolution and high transmission from ion source to the output of the separator. The results of measurements for xenon isotopes with natural abundance are presented and discussed.

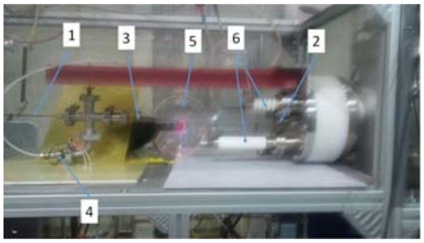
Experimental Setup

I. Isotope separator test bench



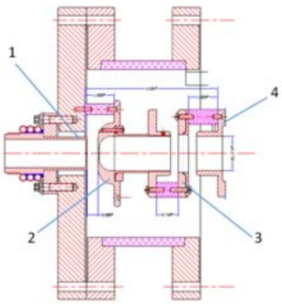
1 – Hollow Cathode Ion Source (HCIS) electronic rack, 2 - HCIS high voltage cage, 3 – beam extraction and gridded lens chamber, 4 – FC1 air stroke, 5 – iris-type shutters, 6 - quadruplet of electrostatic quadrupole lenses, 7 – dipole magnet input slit, 8 – 90° double-focusing dipole magnet, 9 - CsI (Tl) scintillator air stroke, 10 - dipole magnet output slit, 11 – FC2 chamber, 12 - HCIS gas cylinder, 13 – diffusion pump, 14 – turbo pump.

II. Hollow cathode ion source setup



1 – copper anode, 2 – stainless steel cathode, 3 – quartz discharge tube, 4 – pulsed gas injection valve, 5 – plasma ball toy (used to ignite discharge), 6 – extractor and gridded lens HV vacuum feedthroughs.

III. Hollow cathode ion source extraction system



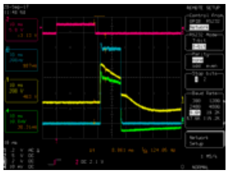
1 – cathode (up to +25 kV)
2 – extractor (-3kV … +8 kV)
3 – gridded electrode (-10 kV … 0 kV)
4 – grounded electrode

Diameter of extraction aperture – 1.5 mm

Gridded lens consists of electrodes 2, 3 and 4

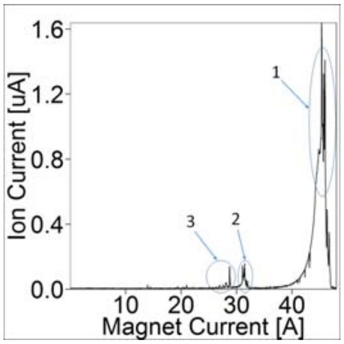
Experimental results

I. Discharge parameters

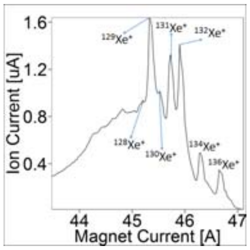


ch1 (yellow) – discharge voltage (up to 1000 V)
ch2 (pink) – gas injection valve trigger pulse
ch3 (blue) – FC1 signal (100 μA)
ch4 (green) – discharge current (300 mA)

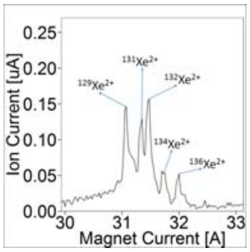
II. Ion beam mass and charge state distribution



Group 1 (95%) (zoomed)



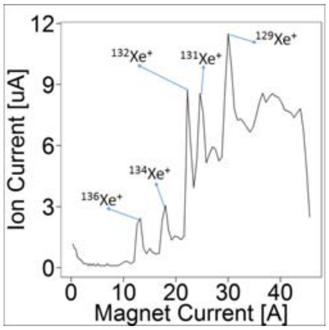
Group 2 (3.3%) (zoomed)



Group 3 - ions from sputtering of stainless steel cathode (Fe, Cr …).

Ion beam energy – 14 keV per charge, dipole magnet output slit width – 1.2 mm.

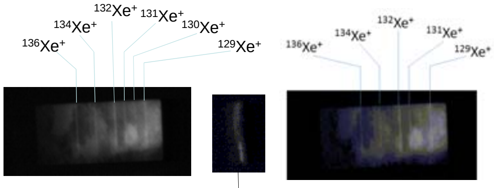
III. Transverse scan of bending magnet output slit



Ion beam energy – 14 keV per charge, dipole magnet output slit width – 1.2 mm.

It was found that interaction of Xe ions with Xe gas atoms downstream of extraction aperture is the reason for the background observed. The signal-to-background ratio was significantly improved by operating an iris-type shutter closest to the HCIS and installing an additional turbo pump with pumping speed 250 l/s downstream of the shutter. Additional enhancement of pumping speed at the output of HCIS is planned in the future to further suppress this effect.

IV. Scintillator images

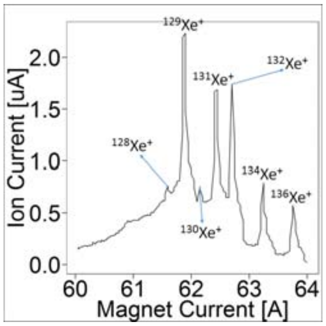


Lower ion beam current — Higher ion beam current

$^{136}Xe^{+}$ ion beam selected by dipole magnet output slit

V. Mass distribution with low background

As a result of shutter implementation, improvement of differential pumping, and boosting the ion beam energy, the background was significantly suppressed:



Ion beam energy – 25 keV per charge, dipole magnet output slit width – 0.6 mm.

VI. Currents of different Xenon isotopes

Isotope Mass, a.m.u.	Natural Abundance, %	Measured Percentage, %	Current, μA
128	1.9	1.6	0.53
129	26.4	26.4	9
130	4.1	1.8	0.61
131	21.2	24.0	8.2
132	26.9	22.8	7.8
134	10.4	15.2	5.2
136	8.9	8.2	2.8

Conclusion

It was demonstrated that an isotope separator based on a hollow cathode ion source coupled to a double focusing dipole magnet can provide beams of single isotope of gaseous elements. Furthermore, currents high enough were achieved to fully fill the RHIC EBIS trap capacity in the slow injection mode. All seven stable isotopes of xenon were fully resolved and beam currents of five most abundant species in the range of 2.8 – 9 μA have been measured.

CsI (Tl) scintillator has high enough sensitivity to visualize ion beams with energy above 14 keV and μA-level current. Efficient tuning of ion beam optics to achieve simultaneously high isotope resolution and good transmission became possible due to beam visualization at the plane of output slit of dipole magnet.

Separation of isotopes of metal elements will be tested in the future using zirconium with natural abundance.

Acknowledgments

This work has been supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy, and by the National Aeronautics and Space Administration.