REPORT ON EBIS DEVELOPMENT AT TEXAS A&M

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Abstract

The general design and operation of a 20 cm EBIS are described. Although good beam transmission and containment are obtained, charge states are limited to low values by the short neutralization time. Improvements to the source, including new containment tube structure, tripling of the containment region, revised cryopumping system, a fully steerable extractor, and time-of-flight change state analysis system, are being carried out.

General Introduction

This source work is intended to produce beams of very high charge states of heavy ions by development of an electron beam ion source (EBIS). The first design goal is the production of working currents of carbon, nitrogen and oxygen with $q/m = 0.5$ and $q/m > 0.2$ for krypton. A more powerful source, producing fully-stripped neon (at least) represents the second goal.

Because the maximum achievable energy for an accelerator scales as Q or Q^2 for linear or cyclic accelerators, respectively, desirability of the highest possible charge states has always been recognized. Although several improvements in design and also scaling (i.e. higher power and magnetic field) are possible and being carried out, the long-term prospects for production of the highest charge states are limited for Penning sources because of the operating pressure. One of the alternatives to the classical discharge is the EBIS. In such a source a high-density magneto-focussed beam of high energy electrons forms an electrostatic trap in an ultra-high vacuum environment to contain the atoms of interest, which are then ionized by multiple collisions with the primary electron beam. The axial configuration of an EBIS is favorable for extraction and for beam quality, and it has a very long lifetime as compared to other heavy ion sources. The most advanced realization of the EBIS is represented by the sources of E. D. Donets, KRION-1 and KRION-2. KRION-1 produces up to 10^{10} of N^{7+} nuclei per pulse and has injected C^{6+} for acceleration to velocities of 8.5 GeV/u on the Dubna synchrophasotron.[1] The physical and electronic configurations for an EBIS are shown in Fig. 1a and 1b. A review of the EBIS work and other alternatives to Penning sources for production of high charge states was given at the 1975 cyclotron confernece by Arianer.[2]

EBIS-20

Our approach, up to the present, is to use a high-convergence electrostatic gun structure to inject a dense electron beam through a region of sharply rising magnetic field (the "transition" region) into the (uniform field) ion containment region. We chose a modified Pierce-type gun[3] with a perveance of 2.2×10^{-6} [A/(volt)$^{3/2}$], a convergence of 66 [r^2cathode/r^2beam] and a beam diameter of 1mm. This gun produces a current density up to 130 A/cm^2 without sparking. The 1400 ℓ/s ion-getter pump on the electron gun chamber gives a pressure ~10^{-10} torr after bakeout when the gun is not in operation. The transition region magnetic field closely follows the theoretical[4] profile for a small hole in the high permeability iron shim plate (see Fig. 2) and the electron gun is positioned according to well-known design rules for injection into Brillouin flow.[5] The resulting 1mm diameter beam was transmitted through the 20 cm axial length of our first test source, called "EBIS-20"[6], which has 3mm I.D. drift tubes, with an efficiency which depends on the magnetic field strength. This efficiency is shown in Fig. 3. The increased transmission for B > B Brillouin may be due to several conditions: a small flux linking the cathode, thermal (translaminar) gun effects, small misaligment of the electron gun, and solenoid field errors. The individual double-pancakes of the 20 cm and 40 cm solenoids which we are using were carefully and iteratively adjusted until axial pitch deviations were minimized. However, the residual variations of ~1/400 in pitch might be the dominant effect for the observed electron transmission losses. This first 20 cm test EBIS is shown in cross-section in Fig. 4 and the electronic system which it uses is diagrammed in Fig. 5.

The gas to be ionized in the electron beam is injected radially by a 3.2 mm tube placed into the wall of the second drift tube.

The six drift tubes in EBIS-20 have an inside diameter of 3 mm and the four in the containment region have lengths of 32 mm each, while the front tube has a length of 28 mm and the last tube has a length of 19 mm. The tubes each have a gap of about 1 mm between them, and the first tube is mounted into the magnetic shim with an insulator so that it is only about 1 mm from the electron gun anode.

The electron gun cathode potential is varaible from 0 to -3.5 kV, and the anode can be pulsed from the cathode potential to a maximum potential of +4 kV. Separate variability of cathode and anode voltage allows the electron kinetic energy within the trap as a free parameter to be optimized. This method of pulsing the electron gun gives an electron beam pulse with a rise time of 20 μsec., but it has a fall time of 2 msec. The electron beam pulse width is variable from 30 μsec. to 2.2 msec. at a repetition rate of one pulse every 3.3 sec to a pulse every 2.0 msec. The electron gun can also be operated in a CW mode by simply disconnecting the anode regulator from the synchronizer unit.

Trapping and extraction potentials are supplied to the drift tubes from two resistive networks driven by power supplies and adjustable from 0 to +650 volts. The trapping potential applied to each of the end drift tubes is variable independent of the plateau voltage applied to the tubes where the ions are trapped, and the acceleration voltage applied to each tube can be varied by changing the connections of the tube on the resistive network. The containment pulse is variable from 30 μsec to 1.1 sec. Also, the rate at which the confinement potential is lowered is variable from a ramp time of 30 μsec to 1 msec.

For extracting the ions from the electron beam, the constant potential on the electron gun is applied to the ion extractor, with an additional voltage variable from 0 to 0.5 kV added to this potential. This additional potential is useful in preventing the electrons from axially escaping and also helps to focus the ions extracted from within the electron beam in the fringing field of the magnet. The ion extractor, with an inside diameter of 6.4 mm, is adjustable at atmospheric pressure with respect to the grounded electron collector, and the whole extractor-collector is adjustable under vacuum in the fringing field of the solenoid.

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The potentials applied to the three focussing lenses are each variable from 0 to -10 kV, while the potential of the magnetic analysis system, and the acceleration tube connected to it, is variable from 0 to 20 kV. Total current measurements can be performed on a 0° magnet port and q/m spectra can be taken on a 30° port through the analysis magnet.

In order to achieve early testing of beam transmission the cryopumping in the containment region was simplified to a single hollow stainless steel hairpin containing liquid nitrogen. This gives a pressure in the containment region estimated at 5 to 10 times the extractor chamber pressure; the latter runs at ~7 x 10^{-9} torr during operation.

The beam must be monitored at the potential of the analysis system (> 20 kV), so a special floating beam current amplifier was built by the electronics group. The output is coupled inductively through an insulated current loop to a Tektronix P6042 current probe for oscilloscope display. The pickup noise of this system is at the level of 100 nanoamps, due mostly to SCR and motor pick-up on the floating chamber which can be eliminated, while the white noise is of the order of 1 nanoamp.

With only residual gas, a total trapped charge of up to $5 \cdot 10^{9} \cdot$ (e) is seen in the fast (~ 20 μs base width) pulse of positive charge ejected at the end of the containment period when τ for containment is > 2.5 milliseconds (see Fig. 6). This represents approximately 50% space charge compensation in the trap region at an electron current of 0.25 A. The true ionic nature of this fast ejected pulse was checked by applying a retarding voltage, which cut off the pulse when the potential of the trap was reached.

We can see that the trap is quickly neutralized by the residual gas pressure by looking at the fast (containment) pulse amplitude as a function of containment time in Fig. 7a. The neutralization is nearly complete in ~1 millisecond. We can conclude that the extraction efficiency could be around 50% since the trap is so strongly neutralized. Losses are now known to be due to some physical misalignment of the extractor and lenses and to azimuthal magnet field variations at extraction.

Figure 7b shows the q/m spectrum operating with residual gas and Figure 7c shows it for argon feed gas. The relative yields are consistent with the trap neutralization time.

EBIS-40

The experience gained with the 20 cm device served to guide the construction of a higher performance EBIS, which is now being carried out.

The new version has a solenoid approximately 40 cm in length and has no elastomer seals in the containment region, in contrast to the previous version. One of those seals was replaced by a welded joint; this now requires that the containment housing be removed through the electron gun chamber. The other seal has been replaced by a Kapton "H-film" seal which can be baked up to 350°C. The containment tube inside diameter has been increased from 3 to 6.5 mm for improved pumping, alignment and beam transmission. The new containment tube structure is a single unit (Fig. 8) which inserts into the containment vacuum shell. This allows complete external optical alignment of the tubes before placing them in the source. The extraction region has been completely revised. We now use an internal magnetic shield between the containment region and the electron collector to greatly shorten the transition region at extraction. The long exit transition region in EBIS-20 caused steering problems and phase-space distortion of the emergent beam. This shield also increases the fraction of the solenoid having a field sufficiently uniform for containment to 0.8. The collector is not moveable, but the ion extractor is bellows-mounted and is completely adjustable in position and orientation, and can steer the beam to compensate for small azimuthal asymmetries. It also incorporates an easily-modified gap lens system which can be adjusted to the actual optical properties of the extracted beam. Because of the excessive time required for a magnetic analysis scan, charge-state analysis will be done by time of flight on this device. This analysis system will (a) use a relatively compact length (<2 m), (b) use a relatively short chopping time (<30 ns), (c) require low acceleration (<10kV) and (d) will resolve charge states up to ~50 through the help of velocity spread-compensating optics.

The gas feed tube is finned to reduce neutral pressure within the containment region by a significant factor. Also, an additional timing circuit has been added to the electronics in order to move the containment potential boundary away from the gas injection tube when sufficient quantities of low-charge state ion have been trapped.

The helium cryosystem has gone through another redesign because of the change in assembly/disassembly (i.e., through the electron gun box). It now (Fig. 9) will rely on conduction rather than flowing gas through a hairpin. A shielded rectangular rod of OFHC copper has sufficiently good heat conduction at 20°K that a gradient of a few degrees will accommodate the radiation and pumping heat load when it is cooled from the extractor region. Cold helium to this feed-thru will be supplied by a "Heli-Tran LT-3-110" transfer system,[6] or by a laboratory-contructed transfer line. These modifications should lead to pressures of ~10^{-10} torr in the containment region, good extraction efficiency, and the desired high-charge states suitable for cyclotron injection.

References

1. E. D. Donets and V.P. Ovsyannikov, Dubna Report P7-10438 (1977).
2. J. Arianer, Proc. 7th Int. Conf. on Cyclotrons and their Applications, Zurich (1975), Birkhaüser Verlag; Basel, p. 341.
3. Hughes Aircraft, Electron Dynamics Division, Torrance, Ca. Model 112-2B.
4. V. Bevc., J. L. Palmer and C. Susskind, J. Brit. IRE 18, 696 (1958).
5. K. Amboss, IEEE Trans. ED-16 897 (1969). J. P. Molnar and C. R. Moster, Bell Tech. Rpt. MM51-2940-1 (1951).
6. R. W. Hamm, Dissertation, Texas A&M, University (1977). Cf also: IEEE NS-23 897 (1976), IEEE NS-22, 1013 (1976), GSI-P-3-77 (Darmstadt, W. Germany) (1977).
7. Air Products and Chemicals, Inc., APD Cryogenics, Allentown, PA.

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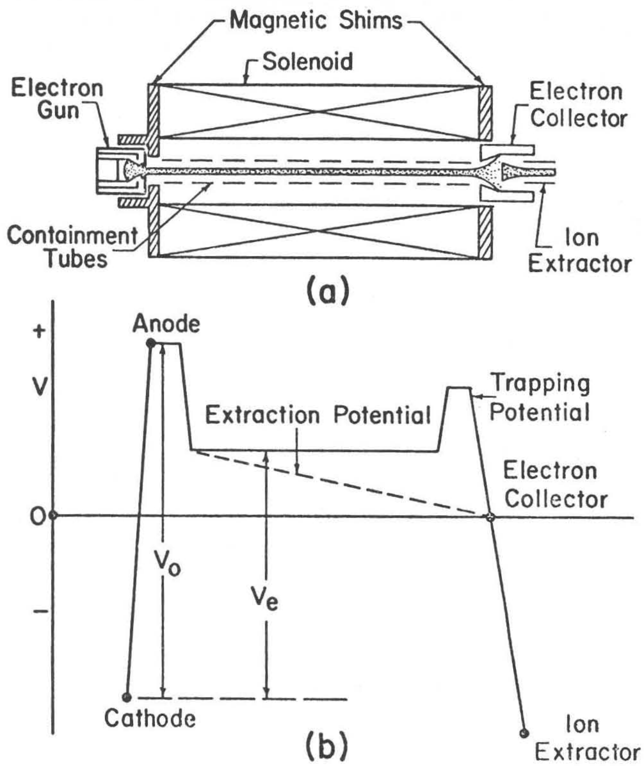
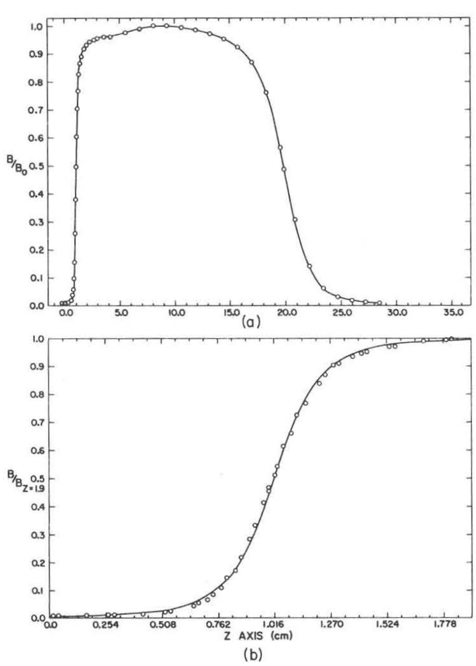
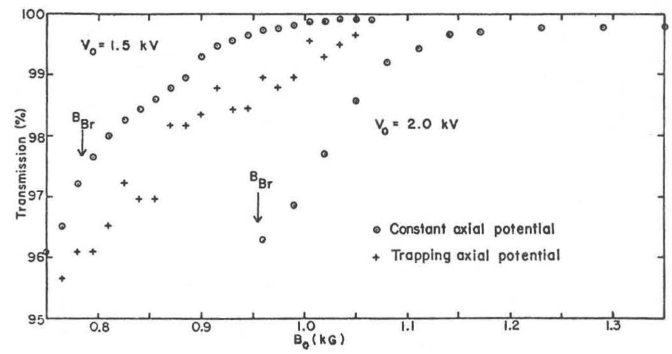


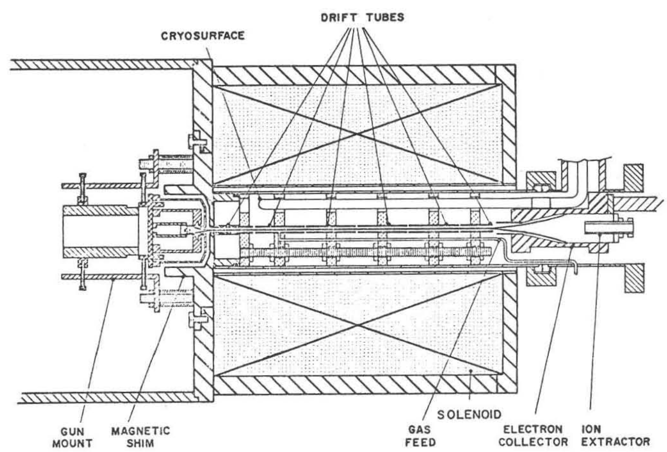
1. A physical (a) and electrical (b) schematic of an EBIS.



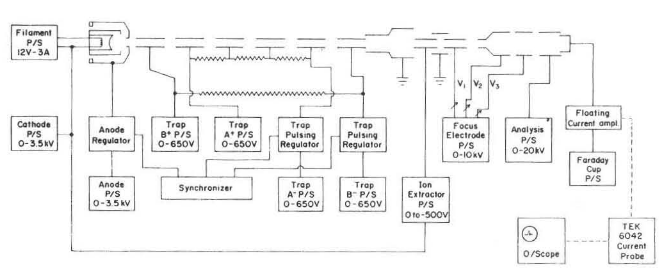
2. The axial field profile of the 20 cm solenoid. The curve for the entrance data is the idealized prediction (Ref. 4).



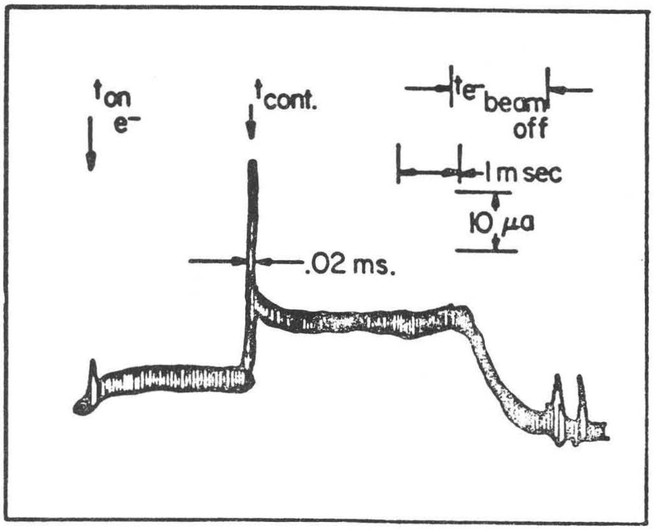
3. Electron beam transmission efficiency as a function of solenoid field strength.



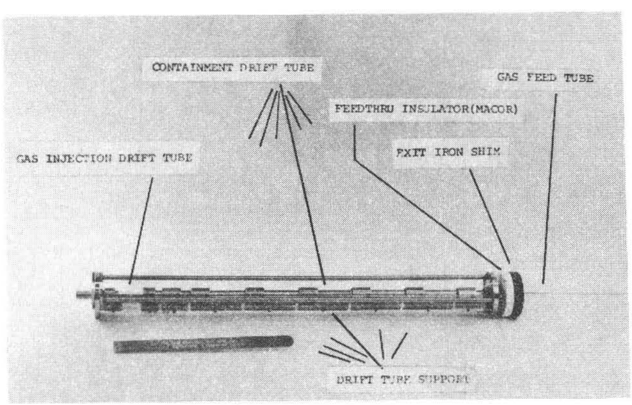
4. Cross-section view of EBIS-20.



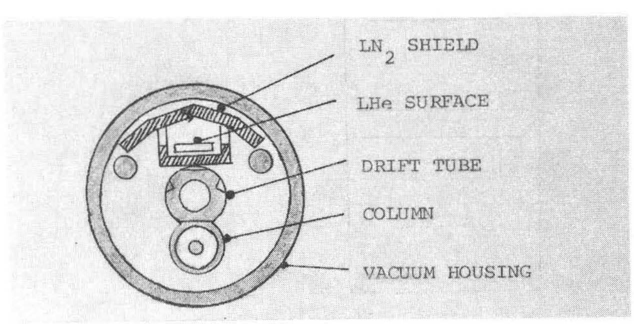
5. Electronics control system.



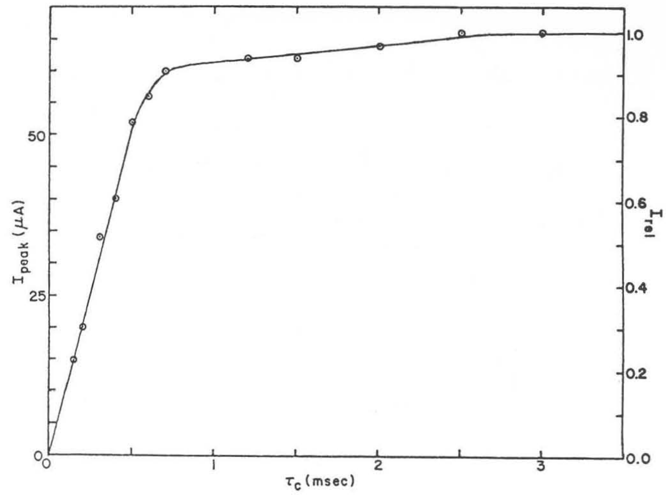
6. Total ion current pulse on a Faraday cup located after the extraction system.



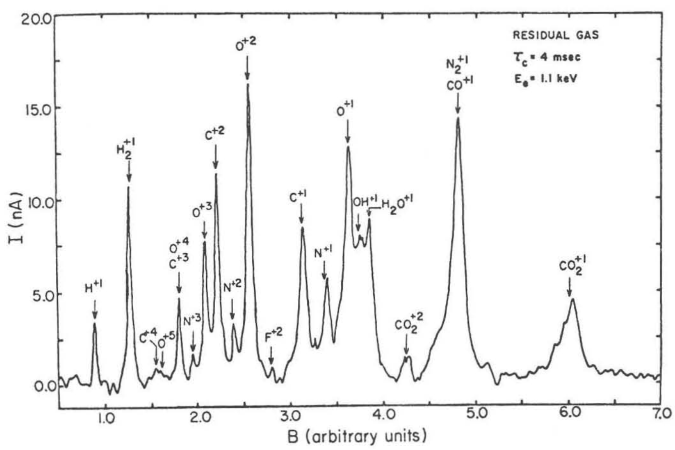
8. Containment tube structure for 40 cm EBIS.



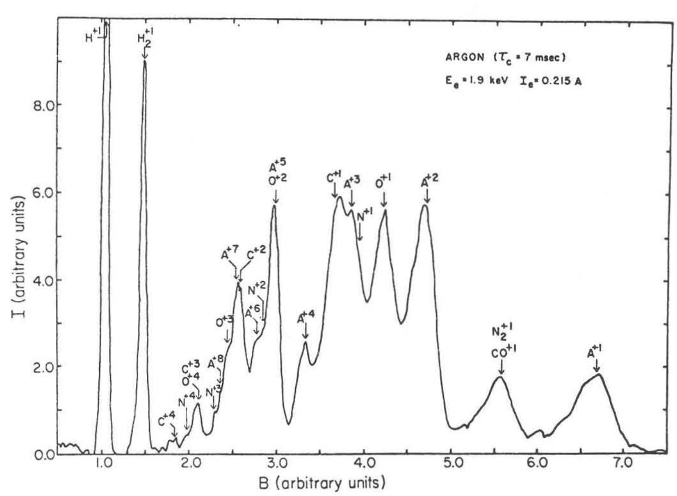
9. Cross-section of EBIS-40 containment region.



7.A Fast pulse (containment ions) peak amplitude as a function of containment time.



7.B The q/m spectrum with no feed gas



7.C The q/m spectrum with argon gas feed