Charge Breeding of Ion Beams ◇

O. Kester , D. Habs, F. Wenander [a], P. Delahaye [a], T. Fritioff [a], M. Lindroos [a], J. Cederkäll [a], F. Ames [b], G. Huber [b], C. Barton [c], K. Connell [c], D.D. Warner [c], R. Becker [d], M. Kleinod [d], T. Lamy [e], P. Sortais [e], and the charge breeding RTD-collaboration
[a] CERN, CH-1211 Geneva 23, Switzerland
[b] Johannes Gutenberg Universität, D-55099 Mainz, Germany
[c] CLRC Daresbury Laboratory, Warrington,Cheshire, WA4 4AD, UK
[d] IAP, Universität Frankfurt, 60325 Frankfurt, Germany [e] LPSC-ISS, Grenoble, France

The capability to raise the charge state of the radioactive ions before injection into an accelerator leads to an enormous reduction of construction and running costs of the accelerator and of the infrastructure. In addition it allows in principle to accelerate ions from all regions of the nuclear chart to the same energy per mass unit. Therefore the charge breeding technique will be applied for the MAFF post accelerator. The charge breeder system is part of the beam preparation of the singly charged radioactive ions for injection into the post accelerator. Two charge breeding schemes are under examination using two types of ion sources capable of reaching the required charge states. These sources are the Electron Beam Ion Source (EBIS) and the Electron Cyclotron Resonance Ion Source (ECRIS). Both breeding systems are present at ISOLDE. There is the unique possibility to carry out charge breeding experiments with radioactive ions beams in order to compare both breeding systems. The goals of the research with charge state breeder systems are to test, characterize and develop the best charge breeding scheme and demonstrate its suitability for incorporation in the final specification of a European RIB facility. In addition the investigation of sufficient separation of the radioactive ions from contaminant ions from residual gas which are produced in the charge breeding devices is required.

The REX-ISOLDE charge state breeder serves already highly charged radioactive ions for experiments with REX-ISOLDE [2]. It is based on an EBIS. Measurements in the past two running periods have been carried out to determine beam emittance, efficiency and breeding time. To match the ISOLDE beam of 30 π mm mrad to the EBIS acceptance of 10 π mm mrad, a large Penning trap, the REXTRAP [3], is installed in front of the EBIS. For high intensities space charge effects start occurring for more than 10^5 ions/pulse, with an efficiency decrease and emittance increase as a result. That means, presently the Penning trap-EBIS concept has a limited ion throughput of $\sim 10^8$ ions/s [4]. The maximum capacity of the EBIS is given by the space charge of the electron-beam trap inside the EBIS. The REXEBIS has a theoretical capacity of $\sim 5 \cdot 10^{10}$ charges/pulse. Assuming only radioactive ions in the beam gives that $3 \cdot 10^9$ Na^+ can be charge bred to Na^{8+} per pulse. This is one order of magnitude larger than the number of ions that can be accumulated in the Penning trap.

The extracted charge-bred ions have a charge state distribution, with approximately 25% of the ions in the main charge state. Only one specific charge state is selected so the inherent efficiency is typically <30%. The best attained efficiency result for the REXEBIS, including beam transport from trap to EBIS, EBIS injection-breeding-extraction and the mass separator, is >10% for potassium breeding. The average efficiency over the whole range Li to Cs is between 5 and 10% [2], and for higher intensities the efficiency can drop to as low as 2%. A trap efficiency of $\sim 40\,\%$ should be included. The mean charge state is easily selected by simply varying the breeding time. In the REXEBIS one reaches a mass-to-charge ratio of 3 to 4 for A<50 within less than 20 ms. For heavier elements, for instance ^{133}Cs, a mean charge state of 32+ was reached within 150 ms with the source's present performance. The breeding time is inversely proportional to the electron-beam current-density of 150 A/cm^2 in the REXEBIS. That means a higher electron current not only increases the space-charge capacity of the EBIS but also decreases the breeding time.

The geometrical emittance of the REXEBIS has been measured as $\sim 10\pi$ mm mrad (95% at 20 kV), but the value is strongly dependent on the ion neutralisation of the electron beam. For longer confinement times and increased neutralisation level of the electron beam, the emittance amounts to $\sim 90\pi$ mm mrad (see fig.1). The purity of the extracted beam is of high importance for most experiments. The REX-ISOLDE achromatic mass separator has a limited q/A-resolution of 100-150, which is not always sufficient to resolve a radioactive peak from a close stable ion peak originating from residual gas ionisation. Then, if possible, a different A/q value has to be selected.

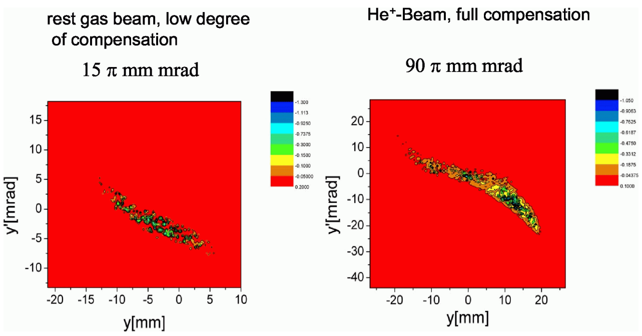

Fig. 1: Emittances of beams from the EBIS measured in front of the RFQ for different degrees of neutralisation

Beside measurements with the REX-ISOLDE charge state booster, a beam line at the ISOLDE GPS has been designed and assembled, which comprises a PHOENIX

◇ work partially supported by the EU under contract HPRI-CT-1999-50003

ECRIS charge state booster, acquired by Daresbury laboratory. The lay-out and a picture of the beam line is shown in fig.2. The injection part of the beam line consists of electrostatic quadrupoles available from the ISOLDE beam line, an implantation chamber for solid state physics experiments, an ISOLDE beam diagnostic box and a double einzel lens in front of the source. The main component of the n+ beam line is the separation magnet that could be borrowed from ISN Grenoble. This one is double focusing which does not require additional optics to focus the beam on the detector. Because there is no possibility to connect the PHOENIX plasma chamber with the ISOLDE high voltage power supply for the target ion source unit, an additional power supply for the biase voltage of the plasma chamber has been acquired, which allows the fine adjustment of the ion injection energy.

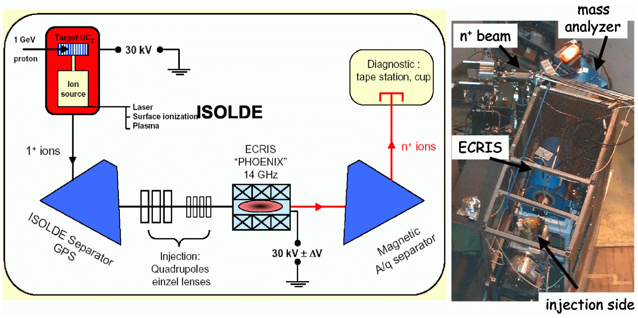

Fig. 2: Schematic and picture of the ISOLDE PHOENIX charge breeding test beam line

One of the main goals in 2003 has been the final assembly of a test beam line for the Daresbury PHOENIX ECRIS at ISOLDE. The main purpose of the charge breeding experiments with the PHOENIX charge state booster at CERN is the investigation of the injection of ions into the ECRIS plasma and the loss mechanism with radioactive ions. In addition the breeding efficiency and the breeding time for different isotopes shall be explored. Charge breeding of injected stable and radioactive ions was planned for the end of the 2003 run at ISOLDE. Unfortunately, the RF window in the wave-guide of the ECRIS was destroyed during the conditioning of the source and the manufacturer was unable to deliver a new window before December. Luckily a new window could be borrowed from a similar ECR at CERN, but only after the 2003 shutdown of radioactive beam production at ISOLDE. Since several radioactive isotopes, among them a few that are suitable for charge breeding test, are available from previously activated targets at ISOLDE during the shutdown period the ECRIS source was run again starting in mid November. There first spectra from a commissioning run have been measured. After successful commissioning, the injection beam line of the ECRIS was finished in preparation of radioactive beam injection and charge breeding of radioactive isotopes. In the first week of December the source was ready to receive ions from ISOLDE. Unfortunately, the high voltage insulator on the ISOLDE ion source failed ad there was no source of radioactive ions for injection and charge breeding in the ECRIS. The charge breeding tests had to be postponed until the restart of ISOLDE in April 2004.

In order to improve the present charge breeding schemes by narrowing the charge state distributions and by increasing the electron beam capacity for ions, new techniques will be examined in collaboration with the EBIS group of the IAP Frankfurt. The goals are the exploration of ion ion cooling of highly charged ions bred in the EBIS, charge state manipulation by breeding at shell closures and injection into a partially compensated electron beam, a so-called Coulomb-target [5]. The Frankfurt Cryogenic EBIS (MAXEBIS) has been redesigned for high electron current up to 3 A and a new collector has been installed which can sustain 15 kW beam power. The new collector shielding has been examined for magnetic fields of the SC-coils of about 5 T. The magnetic field distribution on axis is in good aggreement with the magnetic field calculations including the saturation of the iron shielding at 3 T. In addition the inner structure of the MAXEBIS has been redesigned, in order to allow higher retardation voltages for beam injection, suppression of Penning discharges and a better pumping of rest gas, by using the cryogenic surface of the cold inner bore of the MAXEBIS cryostat. The construction has been completed and the production is being launched at the IAP workshop. A small Ba^+-ion source has been designed in collaboration with IAP, which will provide beams for the injection of the ions into the MAXEBIS. The source uses surface ionisation on a heated tungsten matrix to provide singly charged ions. A Ba-source-body from HeatWave Labs Inc. of 6 mm diameter, providing 10 mA/cm^2 current density is used. The beam calculation for the ion source has been started and the production of the source is planned beginning 2004.

References

[1] U. Köster, O. Kester and D. Habs Rev. Sci. Instr. **69** (1998) 1316
[2] B. Wolf and F. Wenander *et al.*, Nucl.Instr.Meth. **B204** (2003) 428
[3] P. Schmidt Nucl. Phys. **A701** (2002) 550
[4] O. Kester *et al.*, this report p. 79
[5] M. Kleinod *et al.* AIP conference proceedings **572** (2001) 132