DEVELOPMENT OF THE CRYRING FACILITY

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Abstract

The ECR source now delivers beams to experiments. The EBIS source, CRYSIS, has been used with some radioactive species such as tritium, and uranium. The research groups studying molecules and molecular clusters often request ions that can only be produced in small amounts. Thus, weak beams, less than 1 nA from the ion source, have been successfully injected into the ring and stored. Furthermore fast ramping of the magnets during acceleration is reported.

1 OVERVIEW

CRYRING is a 52-m circumference ion storage ring. Bρ max is 1.44 Tm, giving a maximum energy of $96q^2/A^2$ MeV/u. q and A are ion charge and mass. The injection energy is 300 keV/A if q/A>0.23 so the ions can be accelerated in the RFQ, otherwise 40 keV total energy. 109 different ions have been stored in the ring, 30 different ones the last year.

An EBIS ion source produces highly charged ions up to i.e. Pb^{60+}. It is used both for injection in the ring and for low energy experiments.

A recent addition is an ECR source for medium charged ions, which presently only is used for low energy experiments. The beamline to the ring will soon be finished.

For injection in the ring only we have a beamline for various types of sources for singly charged ions.

A more detailed description of the facility is given in [1].

Some of the experimental programs in the ring are

- dissociative recombination in electron-molecule collisions, where the molecule can be e.g. a three-body molecule, a hydrocarbon as $C_2H_4^+$ or a small cluster as D_5^+ (D is deuterium) or $(H_2O)_4H^+$ [2],
- lifetime studies of metastable levels (in the 0.1-10 s range) in singly-charged metallic ions as Eu^+ or Fe^+ with a ring dye laser system [3],
- collisions between negative ions and electrons,
- laser-induced recombination of p and d with both an optical parametrical oscillator [4] and an eximer dye laser system [5],
- 0.3-5 MeV p-He collisions in a gas-jet target, [6] and
- ordering in electron-cooled Xe^{36+} beams [7].

Examples of experiments after the EBIS and the ECR sources are

- mass measurements of stable isotopes in an ion trap [8],
- charge transfer between highly charged ions and well defined single crystal surfaces
- lifetime studies of metastable states of Ne^{8+} and N^{5+} in an electrostatic trap, a so called Cone Trap [9], and
- ion-atom and ion-C_{60} collisions.

2 ECR

The ECR source at MSL is a single stage plasma device of the HYPERNANOGAN type delivered by the Pantechnik company in France. A solenoidal electromagnetic structure superimposed on a permanent hexapolar field is used to confine the plasma. The operating frequency is 14.5 GHz with a maximum rf-power of 2 kW. The magnetic structure enables a future upgrade to 18 GHz. Extraction voltages of 30 kV are possible. The source is equipped with three different injection systems, gas only, furnace for melted metals, and sputtering for metals and compounds. It is capable of producing DC beams of highly charged ions of intermediate mass and intermediately charged ions of high mass, as well as single charged and molecular ions. The ECR source will therefore serve as a good complement to the electron beam ion source as an injector for the accelerator and storage ring within the CRYRING facility, as well as directly for atomic and surface physics experiments.

In order to increase the energy of the produced ions, the ECR source is mounted on a 300 kV high-voltage platform. With this arrangement it will be possible to deliver high currents of a wide variety of ion beams, with energies up to 330q kV. Also located on the HV platform, and separated from the ECR source by an einzel lens, is a 102° double focusing analyzing magnet. The magnet is followed by slits, a Faraday cup, steering plates, a quadrupole doublet and finally the acceleration tube that will bridge the beam line on high voltage with the rest of the beam transport line on ground potential. Due to space restrictions and ripple and leakage current considerations the 300 kV platform is separated in two units. The 350 kVA motor-generator unit and 300 kV, 2.5 mA Glassman high voltage supply is placed in the power-hall and connected to the ECR platform by 40 m long high voltage cables. The ion source platform is mounted on 100 cm porcelain insulators and is fully enclosed in a metal cage. In order to limit the risk for flashover and to protect personal from high-voltage, the inner cage will in addition be enclosed in an outer cabinet, separated at least 60 cm from the inner shield.

The total length of the beam line from the ECR source to the storage ring is approximately 35 m, and it is situated on an elevated balcony level. In addition to the main beam line to the storage ring the beam line systems includes two extra lines where ions can be extracted to experiments close to the ECR source. These beam transport lines are completed and parts of it have been taken into operation.

For some time now the ECR source has been delivering ions to three different low energy experiments (see the list earlier). An advantage with the ECR ion source compared to an EBIS for low energy experiments, but not for injection in the ring, is that the ECR delivers DC ion currents while ion currents from an EBIS are pulsed. Since the source only has been running on a regular basis for a short time only a few ions have been produced for experiments so far. The table below summarizes the ECR ions that have been produced for experiments up to this date. The list also presents the extraction energy and beam currents. Ion currents were measured with a strip-detector situated just after the acceleration tube. In parallel with the ongoing low energy experiments, the final work with completing the ECR HV platform will continue. The goal is to deliver accelerated (up 330 kV) ions to the storage ring this autumn.

1.5q kV ECR ions used in experiments.

Ion	N^{4+}	N^{5+}	Ne^{6+}	Ar^{9+}
I (μA)	2	5	4	3

3.0q kV ECR ions used in experiments.

Ion:	Ar^{8+}	Ar^{11+}	Ar^{12+}	Ar^{14+}	Ne^{8+}	Ne^{9+}	Xe^{17+}
I (μA)	17	3	0.2	0.003	10	2	0.5

3 RADIOACTIVE IONS IN THE EBIS

The EBIS source for highly charged ions has been used to produce tritium ions. An uranium pellet with 10 Curie trapped tritium was purchased and mounted in an oven. Heating to 400° C released sufficient amounts of tritium for the mass measuring experiment. After one week 4%, or 0.14 ml, of the tritium was consumed. When the source was dismounted it was found that some metal surfaces inside the source were contaminated with up to 400 Bq/cm^2. Cleaning with alcohol reduced the contamination 10 times, while a short heating with a hot-air gun removed 99.5% of the tritium. CRYSIS has also been used to produce thorium and uranium beams, but without any measured contamination.

4 NEW SOURCES FOR SINGLY CHARGED IONS

New types and modifications of the available ion sources have been used and tested. The first two types have been supplied by the users.

4.1 Electron impact source

An electron impact source of the Nier type, designed to deliver diatomic molecule ions, such as O_2^+ and N_2^+, with a known vibrational population, was built by AMOLF in Amsterdam[10]. It was used during the experimental week in the spring of 2002 with the fast ramping of the ring magnets, see section 5, mainly to test its properties. It is planned to be used in several experiments in the future. A drawing of the source is shown in fig. 1.

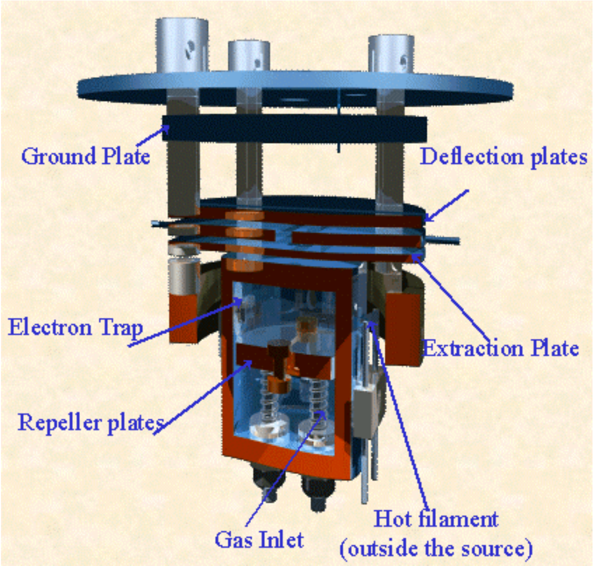

Fig. 1. Schematic drawing of the electron impact source, used to produce O_2^+ ions with a controlled vibrational distribution.

4.2 Molecular beam discharge source

A molecular beam discharge source was built in collaboration with the group of Richard Saykally at the department of chemistry at the University of California in Berkeley. This source will deliver rotationally cold H_3^+ ions with a temperature of 20 K and is capable of delivering of the order of 10^{10} ions per pulse. It will be used with a repetition rate of one pulse per several seconds. The source is planned to be used during the week before this conference and is at present under testing.

4.3 Molybdenum oven for metal ions

An ion source of the Danfysik 911 type, equipped with an oven, was tested during a Ca^+ run, but was not reliable enough to be useful for a one-week experiment. The problems were mainly short circuits and discharges due to coating of surfaces with Ca and the small dimensions of this source.

For the production of ion species that require the evaporation of salts or pure metals, we have improved the oven that is used for the standard Nielsen source. Previously we have used ovens made of boron nitride, MACOR and ceramic (Al_2O_3) that have worked reasonably well at lower temperatures, up to around 700° C, although one problem was condensation of metal in the colder rear part of the oven where a carrier gas was let in. At higher temperatures another problem was that the ovens often cracked.

The oven used at present is made of molybdenum with a coaxial heating wire (Thermocoax) that can be used up to 1000° C. Furthermore, the cooling by the carrier gas is avoided by letting this gas directly into the source volume via a separate inlet. This source has been used at temperatures above 900° C for the production of Nd^+ from $NdCl_3$. The limitation of the oven in the present design seems to be the maximum temperature of the heating wire.

4.4 Heavy Ions

The requests to use heavier ions in the ring poses new problems for us to solve. It is not always straightforward to identify the desired mass after the 90º bending magnet after the source. The mass calibration can become uncertain since the ion energy depends on the plasma potential in the source, which can vary with the conditions in the source. To increase the lifetime of the source as well as the yield of the desired ions, the gas can be pulsed into the source and then the discharge voltage in the source changes during the pulse. This can give rise to a variation of the position of the beam spot after the bending magnet which can be of the order of one mass unit for ions with masses around 100. In one case we were looking for $C_7H_7^+$ ions with mass 91. A peak was found and transported into the ring, but there were no signs of recombined ions, a signal that should have been strong in this case. It seems probable that the ion was $^{181}Ta^{2+}$, since tantalum is the material in the filament wire.

5 THE RING

5.1 Weak Beams

In some of the cases with exotic ions the ion currents are very low, and we have stored beams with less than 1 nA current from the ion sources. For $(NO)_2^+$ and D_5^+ only 500 pA could be produced in the source. The setting up of the injection line and the ring is difficult with such low intensities. We usually use scaling of the magnets, so we set up the injection line and ring for an ion with higher intensity and q/m in the vicinity. One example is the D_5^+ case where the ring was set up with Ne^{2+}. This practice has been successful in many cases.

For electron-ion collision experiments the mass limit is set by the electron cooler. The electrons should have the same velocity as the ions, and the electron current depends on the energy to the power of 1.5, so for heavy ions the both the electron energy and the electron current become very low. The present low-energy record in a successful experiment is 7.9 V, 0.06 mA for $C_6D_6^+$ with mass 84.

5.2 Fast ramping

Recently fast ramping was used in an experiment in CRYRING for the first time. It was originally planned to be able to do extracted beam experiments with a good duty factor, but extraction has never been implemented. In this case, one wanted to study a metastable level in O_2^+ with lifetime either around 300 ms or less than 100 ms according to different theories. However the usual time for acceleration is 1 s, but with fast acceleration it could be reduced to 0.16 s. During this time the dipole field is ramped from 0.1 T to 1.2 T.

One of the dipole chambers is considerably larger than the other and the effect of the eddy currents becomes large in the very beginning of the ramp. This effect was compensated by making a short bump of the closest horizontal correction dipole magnet. Preliminary evaluations of the measurements indicate, however, that the lifetime is shorter than 50 ms, and could not be measured.

5.3 Ordered Beams

We have observed sudden transitions to an ordered state in weak (5 000 ions or less) beams of electron-cooled highly charged ions. This transition can be seen even when the average distance between the ions is approaching 1 m. In ref [6] the observations are described in more detail, as well as a model based on measurements of the Schottky power. According to this model the maximum number of ions that can exist in a one-dimensional ordered string is limited by that the thermal longitudinal motion should overcome the electrostatic repulsion. In CRYRING this theoretical limit is around 9 000 Xe^{36+} ions.

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