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COMMISSIONING OF THE DOUBLE ELECTROSTATIC STORAGE RING DESIREE

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Abstract

DESIREE, the double electrostatic storage rings in Stockholm, is now commissioned and used for experiments. The two rings, inside a double walled cryostat, are cooled to around 11 K and are routinely used for storage of both negative and positive ions with lifetimes of several minutes.

INTRODUCTION

DESIREE is installed at the Physics Department of

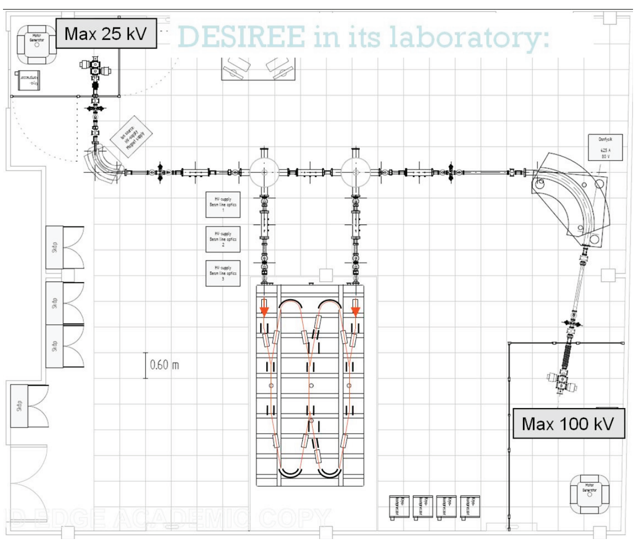

Figure 1: Layout of the DESIREE lab.

Stockholm University and consists of two electrostatic storage rings with one common straight section. The two rings have a similar circumference, 8.6 m, and the length of the common straight section along which stored ions can interact is about 1 m. The storage rings are built inside a cryostat which is cooled to around 11 K by four cryogenerators (Sumitomo RDK-415D). This low temperature in combination with the unique double ring structure results in a powerful machine for studying interactions between cold molecular ions close to zero relative energy. Two injectors are able to supply positive or negative ions to both rings. The DESIREE laboratory with its injectors and beamlines is shown in Fig. 1.

Fig. 2 shows the ion optical elements. The two rings in DESIREE are slightly different. To merge the two beams in the common section, two extra pairs of horizontal steerers (D1, D2) are needed in the upper ring in the figure. The space needed for these steerers requires two of the quadrupole pairs (QD) to be displaced compared to the lower ring. As a consequence, the upper ring uses four

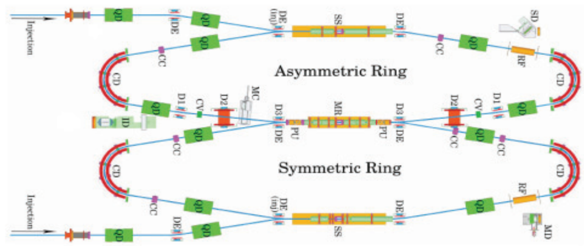

Figure 2: Drawing of the DESIREE optics.

quadrupoles families and is less symmetric than the other ring. It is thus called the asymmetric ring (ring A), although is still has a single-fold symmetry. The other ring, the symmetric ring (ring S) has a two-fold symmetry with two quadrupole families. A more detailed description of DESIREE can be found in ref. [1].

COMMISSIONING

The cooling of DESIREE started in September 2012 and after 15 days the 11 K working conditions was reached. Beam commissioning started with the injection of 10 keV C^- ions into ring S. To find the settings for stored beams in this ring, which is similar to ELISA [2], was easy, due to its large dynamical aperture. The settings were consistent with those obtained from SIMION calculations [3]. After a period of optimization, lifetimes (1/e) of the stored beams of 300 s was regularly obtained.

We knew from the calculations that the dynamic aperture in ring A is much smaller, due to the large distance between the quadrupoles closest to the beam merging section. Indeed, storing ions in the asymmetric ring proved to be a rather more challenging task and the settings for storage differed considerably from those the SIMION calculations. The disagreement may be caused by an imperfect modeling of the elements and/or shortcomings of SIMION in performing the particle tracking. We tracked the ions for 1000 turns in each ring.

A key feature of electrostatic elements is that for a given ion energy the bending power is independent of the ion mass and accordingly the settings of all the electrostatic elements in both the rings and the beamlines are mass independent. As a consequence, changing the ion species to be stored only requires two changes: (1) the selection of the desired masses in the analyzing magnets after the ion sources and (2) the adjustment of the timing of the injection switch to compensate for different flight times from the ion source to the ring. These adjustments are straightforward and many different ions can easily be stored during an experimental period. As an example,

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during a week dedicated to the studies of negatively charged copper clusters, 21 different ions were stored and studied in DESIREE, the heaviest one being the cluster with 21 copper atoms, with a mass of about 1336 u. The current of this ion species after the magnet was less than 1 pA. Such a weak would have been difficult to inject successfully, without being able to use the settings obtained from the tuning of more intense cluster beams.

DIAGNOSTICS

Diagnostics in DESIREE is limited due to lack of space. The main elements are two pairs of Faraday cups and two pairs (horizontal and vertical) of electrostatic pickups. The Faraday cups are installed such that one of them can receive the injected beam directly from the beamline while the other can receive the beam after one turn in the ring. The pickups are mounted in the beginning and in the end of the 1 m long common straight section and are the only means available to measure and adjust the position of the beams to optimize their overlap. At the zero-degree exits of all the three straight secions there are particle detectors, registering neutral particles that escape from the rings. These detectors can be useful instruments for analyzing the properties of the stored beams, although count rates typically are very low due to the excellent vacuum conditions in DESIREE (pressure in the low 10^{-14} mbar range at 11 K).

SIMULTANEOUS MEASUREMENT OF THE POSITIONS OF BOTH BEAMS

An ADC card, NI-6366 with 8 channels and 2 MS/s/channel is used to capture the data from the eight PU amplifiers connected to each of the halves in the two pairs of pick-ups. The amplifiers are built in house with a noise level of 1 nV/√Hz [4].

The two rings have slightly different circumference, so a Fourier transform (FT) of the PU signal clearly show separated peaks for each of the beams, even if they have the same velocity, as can be seen in Fig. 3 b). Consequently, the positions of the two beams in the pick-ups can be measured simultaneously. LabVIEW is used to analyze and display the results, including routines to fit data to get the frequency and amplitude of the peaks. The position is calculated as (difference between FT amplitudes of two halves)/(sum of the amplitudes)*const. The bunching which is due to the single turn injection is sufficient for the measurement. It typically takes 30-50 ms until the beam is debunched. The measured frequency, seen in panel e), is also used for the RF. Acceleration or deceleration is not applied in DESIREE, but RF is applied on a drift-tube for bunching during tuning of the rings.

Figure 3: Screen dump from a PU measurement of 10 keV H^+ in ring A and 10 keV H- in ring S. The graphs show:
a) Raw data from one half.
b) Fourier transform of 20 ms of a). The small peak shows the beam in ring A, the large peak shows the beam in ring S.
c) and d) Horizontal and vertical position in pick-up 1 and 2 in ring S (left) and ring A (right). Ring A is more noisy due to the lower intensity, a few tens of nA.
e) Revolution frequency in rings S and A. Note the small energy variations of the H^+ source which can be seen as a small frequency variation in the red curve.

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VACUUM AND LIFETIMES

For a stored beam of stable particles three mechanisms for particle losses are possible: collisions (single or multiple) with the residual gas, effects from the other stored ions (space charge), and effects of noise on the electrodes, which is similar to when noise is used to excite a beam for slow extraction. The first two are the most important processes for the negative ions stored in the majority of the experiments and tests performed this far. The main residual-gas collision process for the anions is electron detachment which leads to an immediate loss of the particle, but also to a measurable signal in one of the particle detectors if the collision happens along a straight section. This mechanism yields a constant decay rate given by the product of the ion velocity, the residual gas density and the cross section for the collision electron detachment process: $A_{RG} = v\, n\, \sigma$. At modest vacuum conditions or when weak ion currents are stored, this decay process is dominating and an exponential decay with a decay rate of A_{RG} results. For cryogenic operation and storage of tens or hundreds of nA anions, however, we have a situation where the density of ions approaches that of the residual gas. In this case interactions within the ion beam itself leads to higher losses than interactions with the residual gas. As the density of ions changes with time we do no longer find a single exponential decay. The number of ions stored at a time t after injection is then given by [1]:

$$N(t) = \frac{N_0}{(1+r)\exp(A_{RG}t) - r}\ , \qquad (1)$$

where N_0 is the initial number of stored ions and $r = A_{i,0}/A_{RG}$ is the ratio between the initial loss rate due to the ion beam and the constant loss rate due to residual gas collisions. r is proportional to the intensity of the stored beam and we see that for r<<1 we find the well-known exponential behaviour The exponential in the denominator will become dominant after a certain storage time irrespective of the value of r.

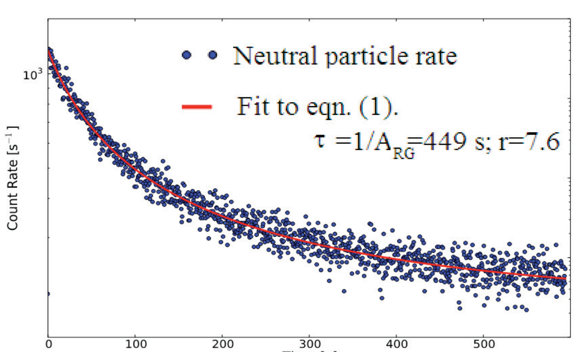

Figure 4: Yield of neutrals from a stored C_2^- beam.

Fig. 4 shows an example with r=7.6. Initially the measured count rate of neutral particles is far from exponential but in agreement with the above expression. From the exponential decay rate, τ, the residual-gas density can be deduced and is typically about 10^4 cm^{-3} for cryogenic operation. Up to 100 nA C^- has been stored. Further details on how to deduce the residual gas density and ion current from the decay curves are found in reference [1].

LASER PHOTODETACHMENT EXPERIMENTS

One of the first scientific projects applying the DESIREE facility is concerned with the determination of the intrinsic lifetimes of bound metastable excited states of anions. In particular we consider the upper J=1/2 fine structure level of an np^5 configuration and the idea of the experiment is to apply a laser with a wavelength chosen such that only ions in the upper level may be photodetached and then to monitor this signal as a function of time after injection. For Te^- and Se^- these lifetimes were measured in a similar manner at the CRYRING storage ring yielding values close to 0.5 s for $Te^-(5p^5)$ and 5 s for $Se^-(4p^5)$ [5]. For the lighter elements sulphur and oxygen the equivalent lifetimes were too long to be measured in CRYRING with its maximum ion storage lifetimes of less than 1 minute for these species. Due to the excellent vacuum conditions in DESIREE the storage lifetimes are much longer enabling more accurate results for Te^- and Se^- and measurements of the $S^-(3p^5\ {}^2P_{1/2})$ lifetime which is of the order of several minutes.[5]

ACKNOWLEDGMENT

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REFERENCES

[1] H. T. Schmidt et al, “First storage of ion beams in the Double Electrostatic Ion-Ring Experiment - DESIREE”, Rev. Sci. Instrum. 84, 055115 (2013).
[2] S. P. Møller and U.V. Pedersen, “Operational Experience with the Electrostatic Storage Ring, ELISA”, PAC’99, New York, 1999, p. 2295 (1999); http://www.JACoW.org .
[3] R. D. Thomas et al, “The Double Electrostatic Ion-Ring Experiment”, Rev. Sci. Instrum. 82, 065112 (2011).
[4] A. Paal, private communication.
[5] P. Andersson et al, “Radiative lifetimes of metastable states of negative ions”, PRA 73, 032705 (2006).