EXTENDING THE USE OF THE CRYRING STORAGE RING

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Abstract

Much of the work performed to develop the storage ring CRYRING, is done with the aim of broadening the use of the ring. New ions and new kinds of ions are continuously requested and much work has been done, both on the existing ion sources as well as on new kinds. The long list of ions stored in the ring includes singly charged atoms, from protons to $^{151}Eu^{+}$; highly charged atoms, up to $^{208}Pb^{54+}$, and molecules, from the lightest, H_2^{+}, to heavier, like O_2^{+}. Recently, also negative ions have been added to the list and, furthermore, clusters of water molecules, the heaviest being $H(H_2O)_4$, with a mass of 73 amu. The adjustment of the electron cooler at the low energies that heavy ions like the water clusters have in the ring, with resulting very low electron currents of less than 1 mA, requires special care. A further important development in the ring is the completion of the gas jet target, which has opened up a new field of experiments, studying collisions between ions and neutral atoms.

1 INTRODUCTION

The storage ring CRYRING was originally designed for heavy ions and singly charged ions with a charge-to-mass ratio, Q/A, above 0.25. During the years since the first experiment was performed in 1993, dissociative recombination of H_3^{+}, the limits of the performance of the ring has continuously been stretched. The existing experimental groups have consistently been requesting new ions and in order to make it possible for new groups to work at the ring, further new types of ions have had to be produced. These requirements have made an increasing amount of work necessary with the ion sources. New types of sources have been introduced, but the old ones have also been used to produce new types ions.

2 ION PRODUCTION

2.1 Highly charged ions

These ions are produced in the electron-beam ion source, CRYSIS. If possible, the atoms to be ionised are introduced by injecting a gas that contains the desired atoms. If a gas with high enough vapour pressure can not be found, the ions are be produced in the external source for singly-charged ions, INIS, and then injected and charge breeded in CRYSIS. In this source, which is of the CHORDIS type from Danfysik[1], gas injection, as well as sputtering and heating of suitable substances in an oven is used.

2.2 Singly charged atomic ions

The singly charged ions can be divided into two categories: the light ones, with $Q/A \geq 0.25$, i.e. a mass less than 5 amu and the heavier ones. The lighter ions are normally produced in a standard way in an electron impact source of the kind developed in the fifties [2]. See Fig. 1. In two cases, B^{2+} and N^{2+}, this source has also been used to produce doubly charged ions.

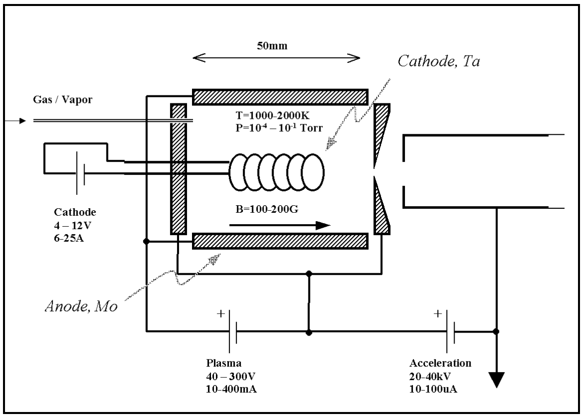

Figure 1: The “normal” hot filament ion source.

The heavier ions pose a special problem. The limit $Q/A \geq 0.25$ originates from discharges occurring in the RFQ when the voltage between the electrodes has to be increased.. Thus, the heavier ions cannot be accelerated. It is, however, possible to focus the beam into the RFQ in such a way that, with a low voltage on the electrodes in the RFQ, most of the beam is transported through the small aperture of the RFQ with only small losses. For these slow ions the accelerating longitudinal voltage is averaged to zero, while only the transverse focussing field is felt by the ions.

Injecting these ions, normally at a total energy of 40 keV, has not posed any major problem. The only equipment that has to be replaced during the low-energy runs is the pulsed injection supply. Already during our first attempts to store slow ions in the ring it was realised, however, that the insulators that were installed in several places in the beam pipe had to be removed to avoid problem with beam instabilities due to charging up of the surfaces of the insulators. The insulator placed inside the current transformer could not be removed and was instead shielded with a stainless steel tube. The slowest ion that we have stored in the ring hitherto is $^{132}Xe^+$ at a total energy of 20 keV, i.e. 150 eV/u.

The production of ions of the non-gaseous substances have been made with the source equipped with an oven filled either with pure metals, e.g. as in the cases of Ca^+ and Eu^+, or with a salt with a suitable vapour pressure, e.g. for Fe^+ when $FeCl_2$ was used.

2.3 Molecular ions

As for the atomic ions, the lighter ions are accelerated in the RFQ, while the heavier are not.

The ions have either been produced by introducing a gas of the molecules to be ionised or by synthesising the molecular ions in the source, normally by introducing a mixture of gases into the source. For the production of molecular ions, a new source, JIMIS, has been introduced. It is a cold cathode source with a geometry as shown in Fig. 2. There are three main motivations for the use of this source:

1. A low temperature is required for an efficient synthesis of several molecules, in particular the water clusters and the dimers of the rare gases.
2. Molecules produced in a high-temperature ion source populate high vibrational levels. For many experiments it is of interest to investigate the molecules in as low vibrational state as possible. The use of a cold source is particularly important when using symmetric diatomic molecules, such as N_2^+ and O_2^+. Since these molecules do not carry a dipole moment, they cannot cool down by emitting radiation while they are stored in the ring.
3. The lifetime of the source is for some cases much less of a problem with the cold source. In particular there is much less coating of the insulators in the source which occur especially when producing molecules that contains carbon. Also the limitations due to sputtering of the filament in the hot source is avoided.

The water clusters have all been produced in this kind of source. The currents are small, in most cases less than a few hundred nA, and for the heaviest, $H(H_2O)_4^+$, only about 30 nA. These low currents are difficult to handle in the injection line and during injection into the ring, but improved diagnostics, such as the introduction of image processing of the video signals from the fluorescent screens in the injection line and low-noise amplifiers for the pick-ups in the ring has made it possible.

2.4 Negative Ions

Since 1999, also negative ions have been used for experiments in the ring. A dedicated ion source for the production of negative ions has been bought [3]. The source is of the caesium sputter type. A schematic drawing is shown in Fig. 3. With this source, most negative ions, atomic, molecular and cluster ions, can be produced by using the proper cathode material. F^-, CN^- and C_4^- have been delivered to experiments that have studied electron detachment caused by electron-ion collisions in the electron cooler.

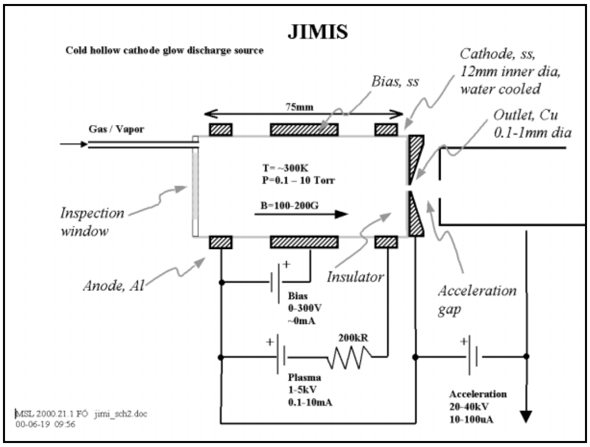

Figure 2: The cold cathode ion source, which mainly is used to produce water cluster and vibrationally cold molecules.

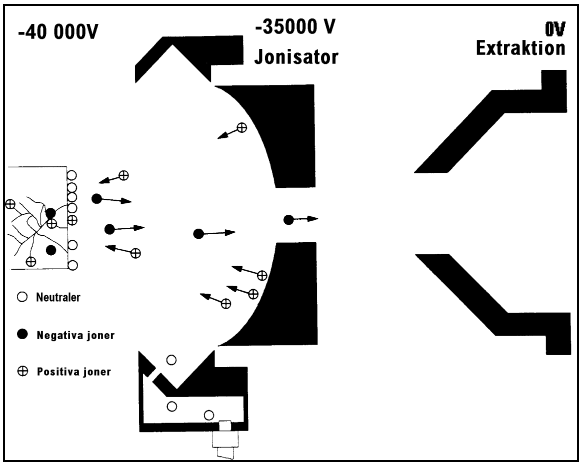

Figure 3: Schematic drawing of the caesium sputter ion source used for the production of negative ions.

3 COOLING AT VERY LOW ENERGIES

The experiments performed with the molecules and clusters have all mainly studied the recombination process, when the ions picks up an electron from the electron beam in the electron cooler section of the ring. Due to the maximum rigidity of the main dipoles of the ring, 1.44 Tm, the maximum energy of the ions is limited to $96*(Q/A)^2$ MeV/u. Thus, the maximum energy of the ions rapidly decreases for increasing mass and, as a consequence, also the electron energy for matching velocities decreases. For several of the heavier molecules electron energies well below 100 eV have been used. The

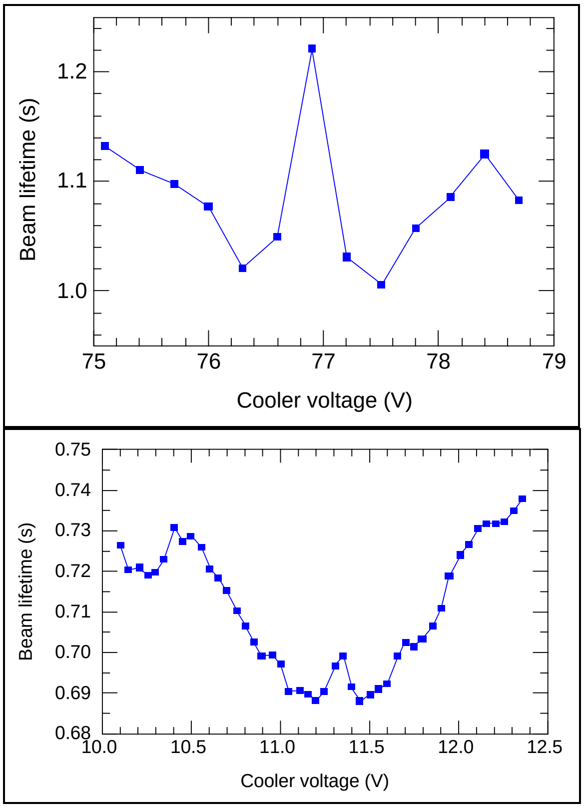

Figure 4: Two examples of the measurements of the lifetime of the beam as a function of the electron energy that are used to find the cooling energy. Upper picture: $C_2H_2^+$ at 142 keV/u, lower picture: $H(H_2O)_4^+$ at 18 keV/u.

lowest accelerating voltage used so far is for the heaviest water cluster stored in the ring, $H(H_2O)_4^+$. With a mass of 73 amu, the maximum ion energy becomes 18 keV/u and the electron energy only around 11 eV. The maximum electron current is proportional to $U^{3/2}$, where U is the electron accelerating voltage, so the electron current becomes very low for these cases. For the $H(H_2O)_4^+$ ions the electron current used was 0.05 mA. No main problems have occurred when gradually going to lower and lower energies. The resolution of the original 20 kV acceleration voltage supply is too coarse though, and a 1 kV supply is now used for the low energies.

A special difficulty arises however. With the low electron currents, signals due to interactions between the ions and the electrons become weak and it is thus difficult to find the electron energy for which the ion and electron velocities are the same. For the lighter ions, with the resulting higher electron currents and also stronger friction force, we normally find the cooling energy by monitoring the increase in signal from the pick-ups when only a weak RF signal is used. The low RF voltage only gives a weak bunching, but when the electron energy is correct, the cooling force narrows the particle bunches and the pick-up signal increases drastically. A different method is used for the heavier ions. The lifetime of the stored beam has been found to vary systematically when the electron energy is varied across the expected cooling energy. Close to the proper energy it decreases and, at cooling energy, there is a peak. Two examples of these measurements are shown in Fig. 3. The reason for this behaviour is not well understood. The decreasing lifetime could be due to the increasing cross section for recombination, while the middle peak could be an effect of cooling, either in the same way as described above or by counteracting losses that are caused by heating of the beam by the noise on the RF signal.

4 THE GAS TARGET

The gas target was completed in mid 1999 and worked essentially as expected. The main problem that was feared, a detrimental effect on the ultra-high-vacuum of around 10^{-11} mbar in the ring, has been entirely avoided. The beam dump, with its three stages of differential pumping and carefully designed apertures, has shown to be so efficient, that almost no effect has been seen on the ring vacuum when the gas jet is on. A drawing of the gas target is shown in Fig. 5 and the design considerations are described in ref. [4]. The first successful experiment was performed during the first weeks of June 2000, when transfer ionisation was observed for protons colliding with the He atoms in the jet for different proton energies between 1-5 MeV.

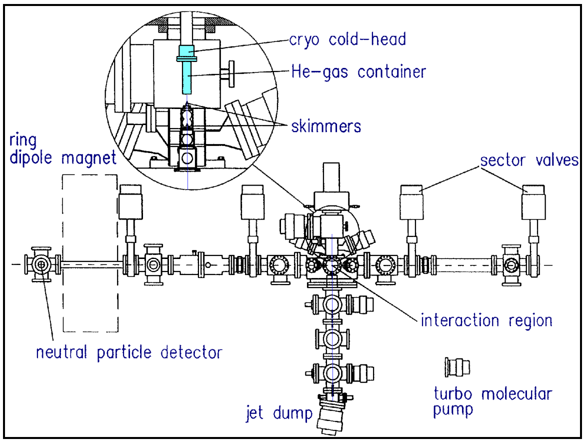

Figure 5: Drawing of the gas target

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