CRYRING PROGRESS: WEAK BEAMS, RARE IONS AND ORDERING

A. Källberg, G. Andler, L. Bagge, M. Björkhage, M. Blom, H. Danared, P. Löfgren, F. Österdahl, A. Paál, K.-G. Rensfelt, A. Simonsson, M. af Ugglas, Manne Siegbahn Laboratory, Stockholm, Sweden

Abstract

Much of the development of the CRYRING facility has been aimed at the production, handling and measurement of weak beams, often of ions that are difficult to produce in the ion sources. Due to the diverse requirements for ions, several different ion source types are in use. To be able to handle and measure the weak beams, the beam diagnostic systems have been improved.

The ECR source is in regular use for single pass experiments and will be used for experiments in the storage ring before the summer of 2003.

The EBIS source has been renovated and upgraded with a new electron gun and will be back in operation in May 2003.

INTRODUCTION

The CRYRING facility consists of a low energy storage ring and a collection of ion sources that can be used for injecting beams into the ring and also for experiments directly at the beam lines from the sources. The available sources are: several types for singly charged ions with different requirements, both positive and negative; an ECR source for ions with moderately high charges and an EBIS source for the production of highly charged ions. The beam line from the ECR source to the ring has been completed, but since the 300 kV platform still requires some work, beams have not yet been transported to the ring. Experiments are planned to use ECR beams in the ring before the summer of 2003. Several experiments have however been using the ECR beam for single-pass experiments at lower energies since 2001. The advantage of the higher currents available have been clear for those experiments that do not need the highest charge states available from the EBIS.

ION PRODUCTION FOR THE RING

Rather exotic requests for ions to be stored in the ring have become a common part of our efforts to run the CRYRING facility. It may be very highly charged ions, like Kr^{33+}, rare organic molecules, like $C_7D_7^+$ and $C_3H_3^+$, or clusters, like $H(H_2O)_6^+$ and D_5^+. Also specially prepared ions are requested, like rotationally or vibrationally cold molecules. Many of the requested ions require careful preparation and sometimes development of methods to produce them in sufficient amounts and in ways that give a reasonable lifetime of the ion sources. For the highly charged ions, the EBIS source has been used exclusively, but for singly charged ions, several different types of ion sources have to be used to comply with all the different ion requirements.

ION SOURCE TYPES

The EBIS source

The EBIS has, to a large extent not been able to deliver beams during the last year. A combination of a much needed renovation and upgrading and a couple of unfortunate technical failures has led to a long period of work on the source while it has not been able to deliver beams to experiments. All this work has just been finished and cooling down of the source has started. Equipped with a new electron gun, it is expected to deliver beams with lower emittance and the transport of the beams will be more efficient. Beams will be delivered to experiments again in May.

Hot cathode source

Several different ion sources are used. The workhorse is a hot filament source with a solenoidal magnetic field [1]. A discharge is created in the source by entering a suitable material from which the desired ion can be created. Quite often a pulsed injection is used, which has the effect both to prolong the lifetime of the source and also often to increase the ion current produced. The substances that are used are gases, liquids as well as solids. Gases are normally straightforward, though special care, of course, has to be taken for gases that are poisonous or explosive. For the liquids, the vapor pressures are regulated by changing the temperatures of the substances. The liquids often have to be cooled to reduce the pressure but in some cases also heating is necessary. In this case also the feed lines into the source, including valves etc., have to be heated to avoid condensing of the liquid in the thin tubes used, which leads to blocking of the tubes and uncontrollable behavior of the source. The solids are heated in an oven that is attached to the source, close to the discharge chamber. If their vapor pressure is sufficient, pure metals is used, e.g. Pb and Ca. More commonly a chloride or fluoride salt has to be used. The oven in use at present is limited to about 900°C and the vapor pressure needed for sufficient ion production is about 10 mtorr. In some cases the use of a noble gas as a carrier gas gives a more stable and reliable operation.

The hot source is suitable for the production of most of the requested ions, also the hydrocarbon ions and ions containing oxygen. The problems associated with these substances in a hot source: internal shortcuts due to soot deposit on the insulators and rapid consumption of the hot filament, respectively, are quite efficiently counteracted by the pulsing mentioned above. At least the need to change source is reduced to at most twice during an experimental week.

Cold cathode source

In some cases, however, a cold cathode source is used. The main reasons for the use of this source are when cluster ions are to be produced and when vibrationally colder ions are needed. The cluster ions are destroyed by the high temperature in the hot source and their formation is also favored by the higher pressure in the cold cathode source. Also with this source pulsing of the vapors that are needed to produce the clusters is used.

Nier type source

Two further ion sources are used when the experimentalists have particular requirements on the vibrational and/or rotational populations of the molecular ions. An electron bombardment source of the NIER type, built at AMOLF, Amsterdam [2], delivers cold ions of symmetric diatomic molecules, such as O_2^+ and N_2^+, with a controlled vibrational population. Since these molecules do not have an electric dipole moment, they do not cool down by emitting infrared radiation while stored in the ring.

Supersonic expansion source

A particular case, ever since it once was the subject of investigation during the first experiment performed in the ring in 1993, is H_3^+. This molecule plays an important role in the production of molecules in interstellar space. To be able to use the measurements of the recombination rates that could be performed in the CRYRING storage ring in calculations of molecular synthesis in interstellar space, the ions have to be produced in a very cold state. With the help of a source utilizing a supersonic expansion technique, developed by the group at the department of chemistry at UC Berkeley led by Richard Saykally, cold H_3^+ molecules with temperatures of 20 – 60 K could be produced. The important results of these measurements in CRYRING have recently been published in Nature [3].

Cesium sputter source

For the production of negative ions, a commercial source of the Cesium sputter type is used. This source is able to produce a wide variety of negative ions by carefully choosing the proper cathode material.

WEAK BEAM DIAGNOSTICS

The success of delivering all these rare ions to the experiments has been made possible due to improvements of the diagnostic equipment, both in the beam lines and the storage ring. In a few cases, beams with currents below 1 nA from the ion source have successfully been transported to the ring, stored, accelerated and electron cooled. Low-noise amplifiers and beam-loss particle detectors have been the main tools for this task. Sometimes the trick of setting up the ring with another ion, which could be produced in larger amounts, and having the same charge-to-mass ratio as the desired one has been used. This procedure helps a lot for the rarest ions. As an example, the use of $^{20}Ne^{2+}$ to prepare the ring for the injection of 0.5 nA D_5^+ can be mentioned. Since many experiments also require a measurement of the stored current in the ring, to be able to measure absolute reaction cross sections, much work has been done to reduce the noise of the AC current transformer. Figure 1 shows an example of a current measurement in the ring. The current transformer used, of the ICT type from Bergoz, has been better adapted to our needs. It now has a noise that is 20 times lower than originally, thus enabling us to measure bunched circulating currents below 1 nA. To obtain this noise reduction, we have replaced the original preamplifier with a higher gain, low-noise one and placed this amplifier close to the detector. Since the current measurement with this type of current transformer has to be performed on a bunched beam, it is done in the beginning of the ring cycle, with the RF voltage on. The count rates of the detectors in the experiments are then normalized to the current measured with the help of a beam-loss detector which measures neutral particles that are lost from the beam at the zero-degree exit after a dipole magnet.

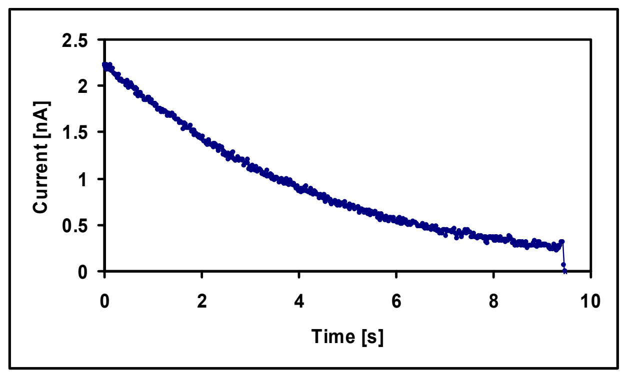

Figure 1: Current of a stored H_2S^+ beam.

ORDERED BEAMS

The phenomenon of a sudden change in the momentum spread of a weak, electron-cooled highly charged ion beam, as seen in the Schottky spectrum, which was originally observed at GSI in Darmstadt, has also been studied in CRYRING. This sudden change of the properties of the beam has been interpreted as a transition to an ordered state and has been observed in weak beams of electron-cooled highly charged ions.

Using coasting beams of 7.4 MeV/u Xe^{36+} ions, we have studied how the particle number at the transition depends on the electron-cooling power (varied by changing the electron current in the cooler). When the cooling is weak it is found that the transition to the ordered state can take place at very low particle numbers—less than 100. Since the circumference of the CRYRING storage ring is 51 m, the particle distance in this case is of the order of 0.5 m. When the strength of the cooling is increased, on the other hand, a kind of saturation is seen, such that ordering with more than about 6000 particles has not been observed. Although this saturation could be due to experimental limitations, there are reasons to believe that it has to do with the properties of the ordered state.

At CRYRING, indications of ordering have also been seen with a bunched beam, looking at the bunch shape with a longitudinal pickup and an oscilloscope. Using an rf amplitude of only 6 mV, sharp transitions from a broad emittance-dominated bunch to a much narrower, approximately 3 m long space-charge dominated bunch were seen when the bunch contained some 400 Xe^{36+} ions. This bunch length and particle number agree well with theoretical calculations of the bunch length for a one-dimensionally ordered particle configuration, and the line density is quite similar to upper limit for coasting beams. Also in the Schottky spectrum a transition was observed, as shown in fig. 2.

Studying bunched rather than coasting beams gives a possibility to control the linear particle density in the ring by just changing the rf amplitude. Thus one could hope to achieve ordered beams with higher densities than previously observed, and one might also be able to observe their “vaporization”. A recent update of our observations can be found in ref. 4.

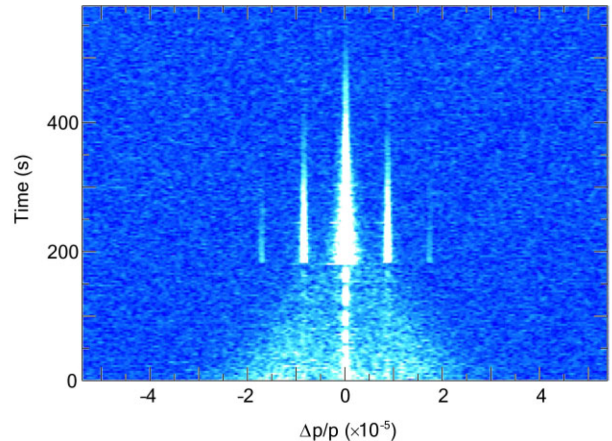

Fig. 2. Schottky spectrum of a Xe^{36+} beam with an rf voltage of 6 mV indicating the observed transition to an ordered state with a bunched beam.

REFERENCES

[1] I. Bergström, S. Thulin, N. Svartholm and K. Siegbahn., Ark. Fys. **1** (1950) 281; K. O. Nielsen, Nucl. Inst. Meth. **1** (1957) 289

[2] C.W. Walter, P.C. Cosby, and J.R. Peterson, J.Chem.Phys. **98**, 2860(1993)

[3] B. J. McCall, A. J. Huneycutt, R. J. Saykally, T. R. Geballe, N. Djuric, G. H. Dunn, J. Semaniak, O. Novotny, A. Al-Khalili, A. Ehlerding, F. Hellberg, S. Kalhori, A. Neau, R. Thomas, F. Österdahl, and M. Larsson, Nature **422**, (2003) 500

[4] H. Danared, A. Källberg and A. Simonsson, J. Phys. B **36** (2003) 1003