EXTERNAL ION SOURCES AT THE KARLSRUHE CYCLOTRON

V. Bechtold, L. Friedrich and F. Schulz
Kernforschungszentrum Karlsruhe GmbH, Institut für
Kernphysik/Zyklotron, Postfach 3640, D-7500 Karlsruhe, FRG

Abstract - Since the successful injection of ECR-produced, fully stripped ions from p-HISKA into the Karlsruhe cyclotron in 1981, the long ECR source HISKA has been completed and tested. First runs of HISKA resulted in charge state distributions with a considerably larger yield of high charge states, e.g. the N^{6+} intensity was a factor of 2.5 higher than that obtained with p-HISKA. The production and injection of fully stripped ions will be reported. Experiments with Li-vapour in p-HISKA demonstrated that at least 10 % of the extracted Li-ions were in the 3^+-state. A special ECR-source for Li-ions has been constructed, details of which will be described. In the beginning of 1985 the 15 year-old Lambshift Ion Source LASKA for polarized deuterons will be replaced by an Atomic Beam Source, delivered by Sentec in Switzerland. The actual polarized beam current will increase from 1 μA to at least 60 μA at a 10 keV injection energy.

Introduction

Since 1971 an axial injection system has been in operation at the Karlsruhe cyclotron. This system allows the injection of beams from the three existing external ion sources. The Penning source for $^6Li^{3+}$ [1] and the polarized source LASKA [2] are extensively used, delivering beams of some tens of nA beam on target. The ECR source HISKA [3] was designed to deliver highly charged ions up to Neon, although at present only fully stripped light ions can be accelerated by the cyclotron. To meet the requirements of future nuclear physics experiments measures were undertaken to increase the current of the lithium- and polarized deuteron beam. A special ECR source for Li-ions (LISKA) has been constructed. In a previous experiment with p-HISKA it had been demonstrated that at least 10 % of the extracted Li-ions were in the 3^+-state. At the end of this year the Lambshift source LASKA will be replaced by an atomic beam source. The new polarized source will deliver a current of almost a factor of 60 more than LASKA.

For all three sources a new ion source building was constructed and consequently a new horizontal beam line was built with an improved vacuum and transport efficiency for the beam.

HISKA

The heavy ion source HISKA, shown in figure 1, is a two stage device. The first stage consists of a permanent ring magnet where the microwaves (14.5 GHz) are injected axially to create a dense plasma in a rather small volume. Only a few tens of watts are required. In the second stage the magnetic mirror configuration is produced by two superconducting coils and a permanent hexapole magnet inserted into the vacuum chamber. The microwave frequency used in the second stage is 7.5 GHz. Initial operation of HISKA was made in the autumn of 1982. In order to study the time behaviour of the plasma the source was operated in a pulsed microwave power mode. Figure 2 shows that within 10 msec of switching on the microwave a maximum of N^+ ions is reached, which decreases within 20 msec to a constant level. The N^{6+} ions, produced in a multi step process, were formed within a longer time (> 30 msec).

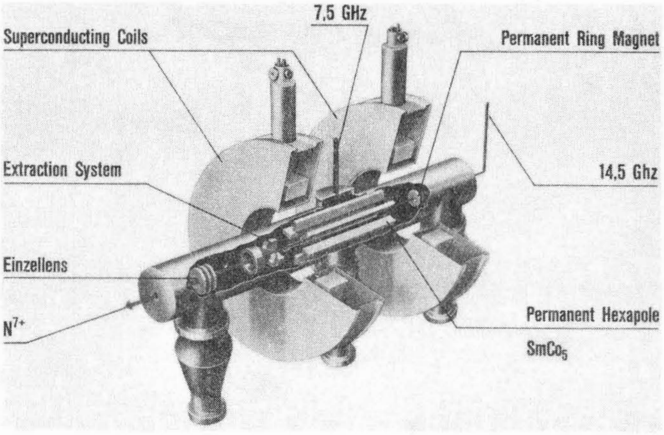

Fig. 1 An artist's conception of the heavy ion source HISKA

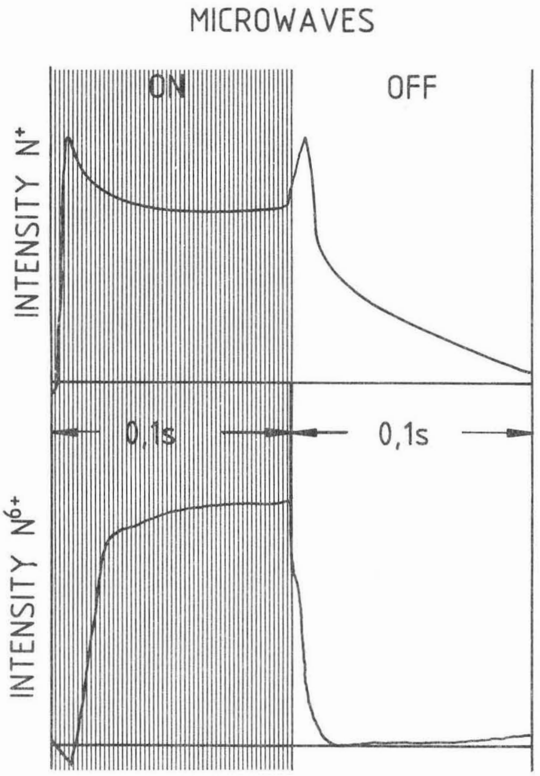

Fig. 2 Life time of N^+ and N^{6+} ions as a function of microwave power

The N^{6+} ions disappear immediately when the microwaves are switched off, whereas the N^{+} ions increase to the initial maximum and can still be observed some 100 msec later.

While operating the source with a microwave power of 1.5 kW, x-rays of up to 100 mrem are produced at a distance of 4 m from the plasma. Consequently lead shielding is absolutely necessary. In figure 3a the shape of the x-ray spectrum of HISKA is shown. This distribution is independant of the microwave power. The maximum intensity is in the region of 60 keV, and decreases to half this value at 90 keV. More than 300 keV x-rays could also be detected. The peak and overall intensity increases likewise with the microwave power (see figure 3b). This behaviour seems to be a property of the special construction of HISKA, ie the permanent hexapole inserted into the plasma chamber. 90 keV electrons are 10 % heavier than the electron rest mass, which causes the resonance surface (cigar shaped) of the heavier electrons to touch the hexapole and hence produce x-rays.

For the optimum output of highly charged ions the source is operated with 1.5 kW microwave power (7.5 GHz) at a neutral gas pressure of $7 \cdot 10^{-7}$ mbar. It is evident that the plasma density cannot be much more than a factor of 2 or 3 times higher than that of the neutral particle density. Hence the corresponding plasma density is in the range of $7 \cdot 10^{10}$ $n \cdot cm^{-3}$, which is far below the cut-off density. The upper curve of figure 4 shows the cut-off density versus microwave frequency. To reach the cut-off density for 7.5 GHz at least 20 kW of power is neccessary. To operate the source with twice this frequency would require about 70 kW microwave power, which would make it virtually impossible to cool the walls of the vacuum chamber, irrespective of the tremendous cost of the transmitter that would be required. Moreover, the neutral gas pressure would not allow the extraction of fully stripped ions.

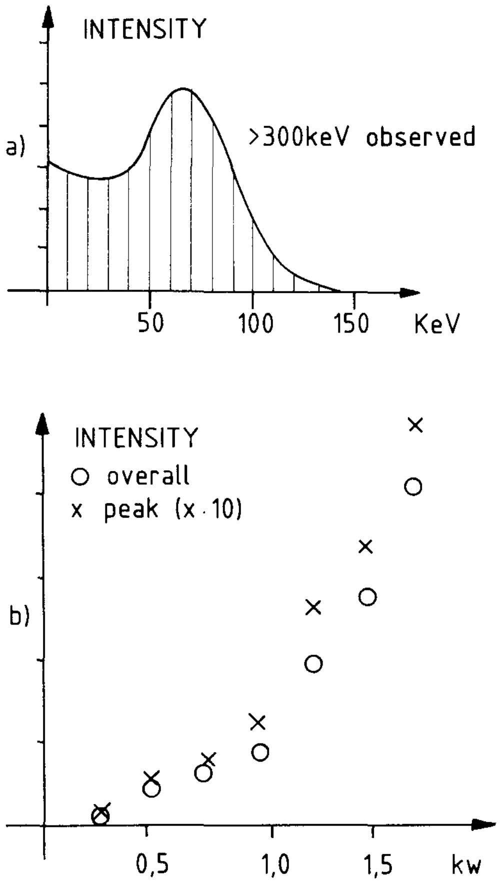

Fig. 3a The energy spectrum of the x-rays from HISKA
3b x-ray intensity as a function of microwave power

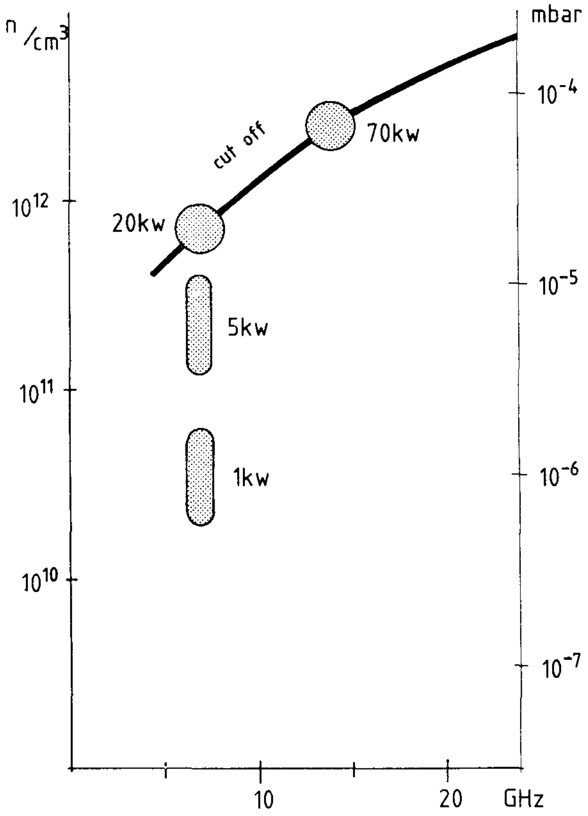

Fig. 4 The plasma density and the corresponding neutral particle pressure versus microwave frequency

From these considerations it is not at all clear whether higher frequencies necessarily lead to a greater output of highly stripped ions.

Upto now HISKA has been operated for a few 100 hours. During this time several improvements were made, including a radially adjustable extraction system, increased pumping speeds in the extraction and plasma stripper regions, together with a new Wien-filter with a higher acceptance and better vacuum. These modifications resulted in much better charge state distributions and higher currents for carbon, oxygen and nitrogen than had been previously obtained. Figure 5 and figure 6 show the charge state spectra for these gases when the source was operated with either N_2 or Co_2. Currents of 600 nA for both N^{6+} and C^{5+} could be produced, compared to the 200 nA obtained from p-HISKA [3] (a 1:3 scale version of HISKA). From this it appears to be favourable to have a larger source.

The injection from the source into the cyclotron was optimized with α-particles from HISKA. 3.3 % of the alpha-particles analysed through the Wien filter could be extracted from the cyclotron. Assuming that the intensity of the N^{7+} charge state is 10 % that of the N^{6+} ions, it can be estimated that the N^{7+} current

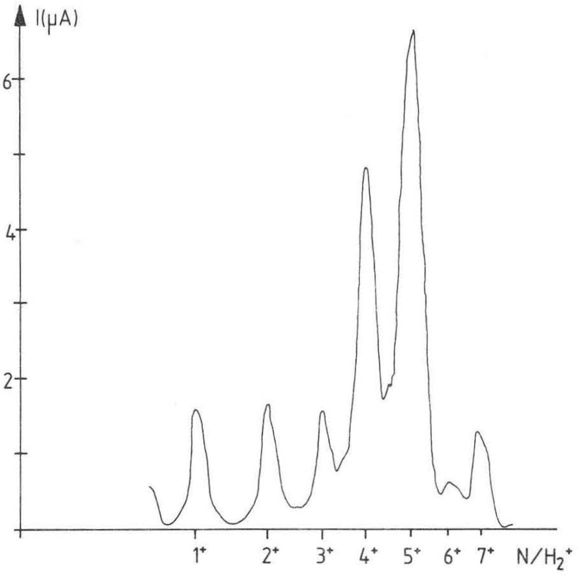

Fig. 5 Charge state distribution for nitrogen

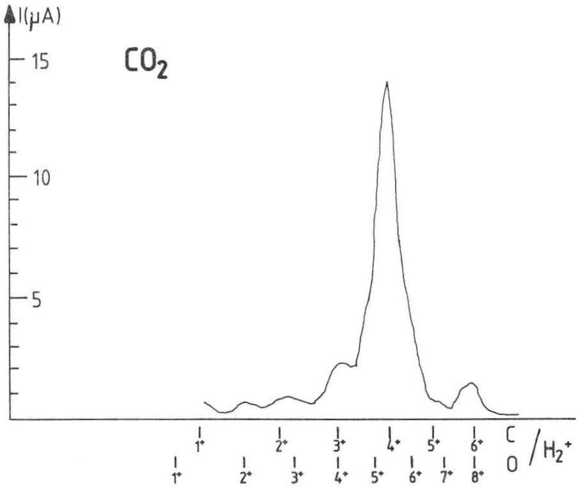

Fig. 6 Charge state distribution for carbon and oxygen when the source is operated with Co$_2$

will be roughly 60 nA. Thus ultimately, one should be able to extract some 2 nA of N^{7+} beam from the cyclotron; this however, has yet to be confirmed.

Last autumn, during such a test run for injection, a sudden rise in the helium boil-off rate within the coils, led to an unacceptably high rate of helium consumption. As a result, continuous runs of the source were no longer possible. This high loss of helium was due to a failure in the cryostats. HISKA is now completely dismantled and the coils have been sent back to the manufacturers. It is planned to set the source into operation again in the middle of this year.

LISKA

Preliminary experiments with Li-vapour in p-HISKA demonstrated that at least 10 % of the extracted Li-ions were in the 3$^+$-state.

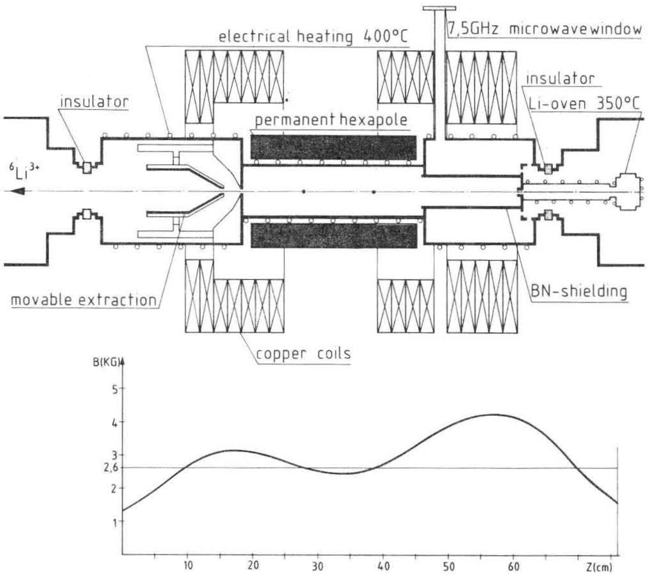

Fig. 7 A schematic layout of the Li-ion source LISKA. The measured field distribution along the axis is show below

Due to this encouraging result a new two stage ECR source LISKA was constructed exclusively for the production of fully stripped Li-ions. The layout of LISKA is shown in figure 7. The first stage consists of an Li-oven that can be heated electrically up to 350^o C and is installed in a vacuum chamber. This vapourizer design has been successfully used in the external Penning source for several years [1]. The evaporated Li diffuses in the heated nozzle of the oven into the second stage. The whole vacuum chamber of the second stage is electrically heated to keep Li off the walls and to achieve the correct vapour pressure of Li.
In the second stage the magnetic bottle is generated by two sets of water-cooled copper coils forming the longitudinal field, and a permanent hexapole sitting outside the ionization chamber. The construction of the hexapole [4] is the same as that used in HISKA. The 7.5 GHz microwave are fed in radially between the first coil set. Here the extraction system is adjustable in the axial direction to meet the optimum extraction condition with respect to the resonance surface of the plasma. The extraction voltage is 10 kV. The source is pumped from each side of the plasma region via diffusion pumps with pumping speeds of 700 l/s. Figure 8 shows a photograph of the new source LISKA mounted on

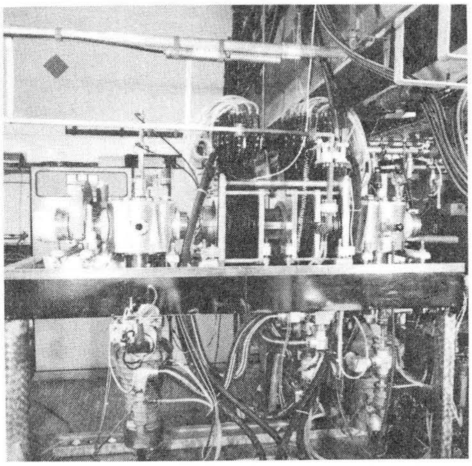

Fig. 8 The Li-source mounted onto the horizontal injection line of the cyclotron

the injection line of the cyclotron. Figure 9 shows a charge state distribution of ^{7}Li-ions from which 3 µA ^{7}Li^{3+}-ions could be produced. First injection into the cyclotron is planned for June this year.

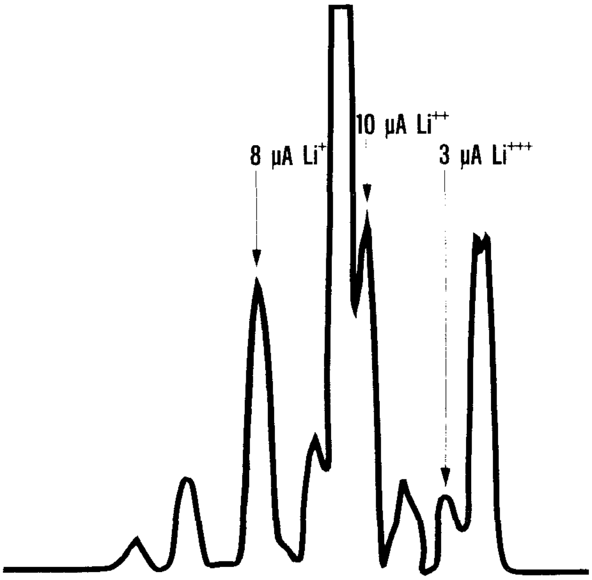

Fig. 9 Charge state distribution of ^{7}Li-ions

Polarized Ion Source PASKA

The new polarized ion source will be of the atomic beam type. The source is designed to deliver ≧ 60 µA of polarized protons or deuterons within an emittance of 500 mm mrad at a 10 keV injection energy. This new source will no longer have diffusion pumps which in the past have turned out to be very disadvantageous, instead only turbomolecular pumps and cryo pumps will be used. This helps to improve the vacuum, keeps the vacuum chambers clean and makes maintenance more easy. Figure 10 shows a schematic layout of the new polarized source. The source is mounted vertically, with the beam leaving the source from the bottom. The installation of the source is planned for the end of this year, and first test runs are foreseen in January 1985. The new source is based on the second generation of polarized sources from ANAC and will be delivered by SENTEC, a Swiss company.

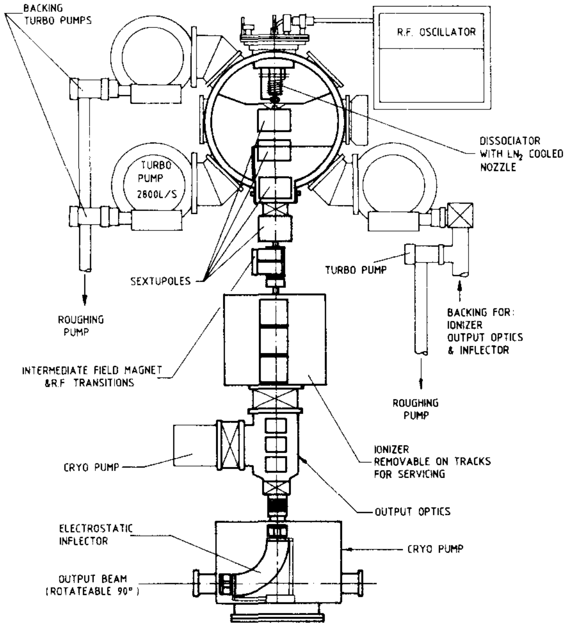

Fig. 10 Schematic layout of the polarized source PASKA

Beam Transport

All three external ion sources are linked to the cyclotron via a 15 m long horizontal beam line and an axial injection system. A schematic layout of the beam transport system with the sources is shown in figure 11. Focusing elements of the horizontal beam line consist of 10 electrostatic einzel lenses spaced 150 cm apart. A cross section of an einzel lens is shown on the left side in figure 11. Since the beam energy is only 10 keV, careful shielding against magnetic fields is neccessary. This shielding is achieved by an iron tube around the beam line. The pumping of the beam transport system is done by 700 l/s diffusion pumps, producing a vacuum pressure of 3·10^{-7} mbar.

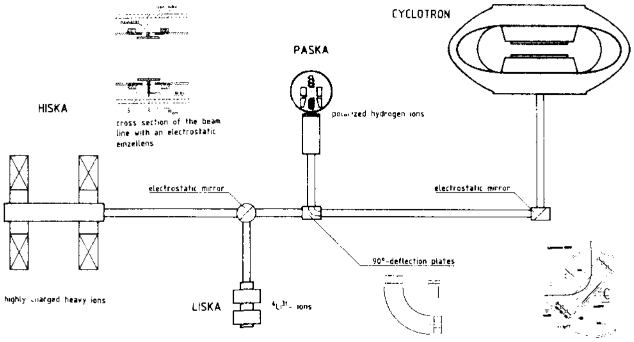

Fig. 11 External ion sources and beam line of the Karlsruhe cyclotron

The beam is deflected from a horizontal to vertical direction with an electrostatic mirror before injection into the cyclotron. The same type of deflection is used for splitting the Li-ions into the main beam line. A schematic view of the mirror is shown on the right side in figure 11. The polarized beam leaving the atomic beam source is bent from the vertical to the horizontal beam line via a pair of 90°-deflection plates. A cross section of this device is shown in figure 11 as well.

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