HISKA, STATUS REPORT AND FIRST INJECTION OF ECR PRODUCED IONS INTO THE KARLSRUHE CYCLOTRON

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Abstract. - Since the beginning of 1979 an ECR-ion source for fully stripped light ions up to neon has been under development. This source is designed for the Karlsruhe Isochronous Cyclotron which accelerates e/m = 1/2-particles up to 26 MeV/N.

The present design of the two stage device HISKA (Heavy Ion Source KArlsruhe) are presented. Special properties such as magnetic mirror geometry, vacuum configuration and microwave feed-in are discussed.

Parallel to this work a small scale version of HISKA, the ECR-ion source p-HISKA was built as a test facility. About 25 nA of fully stripped nitrogen ions could be produced. In early spring 1981 we succeeded in accelerating ${}_{14}N^{7+}$-ions to an energy of 364 MeV.

1. Introduction.

- The Karlsruhe Cyclotron is a fixed frequency machine which accelerates ions with Z/A=1/2 to an energy of 26 MeV/N. Since 1971 an axial injection system has been in operation 1) allowing injection of polarized deuterons from a Lambshift source 2) and fully stripped Lithium ions from a Penning source 1).

This injection system was designed to accept an ion beam with a normalized emittance (ε β) of 0.5 π mm mrad. With the exsisting external ion source, 10 % of the dc-beam could be extracted routinely from the cyclotron using a bunching system 1) with a bunching factor of 3. The design aim for a suitable heavy ion source at the Karlsruhe Cyclotron is to deliver fully stripped ions in continous regime with several 100 pnA and an emittance of less than 500 mm mrad at 10 keV/N injection energy. In order to get a bunching factor of 3 an energy spread of less than 30 eV/N is required.

2. HISKA.

- The production of highly stripped ions with the two stage ECR source 'Supermafios' was demonstrated by Geller several years ago 3). Based on these results it was decided in 1978 to develop for the Karlsruhe Cyclotron an ECR source delivering fully stripped light heavy ions up to neon.

The main features of the Karlsruhe ECR source HISKA (Heavy Ion Source KArlsruhe) are: low power consumption, great flexibility, good vacuum conditions and easy access for diagnostics.

Figure 1 shows a schematic drawing of the two stage device HISKA. In the first stage a plasma is created and in the second stage ionisation to high charge states takes place. The necessary high electron energy and density is achieved by microwave heating in a magnetic bottle.

The first stage consists of Mini ECR-source, where the cold plasma is produced, and a differential pumping system. Figure 2 shows the Mini source in detail. The ECR zone is inside a permanent ring magnet made of Samarium Cobalt with an axial field strength of 5.2 KG in the middle of the 10 mm diameter inner bore. The magnet has an outer diameter of 70 mm with an axial length of 20 mm.

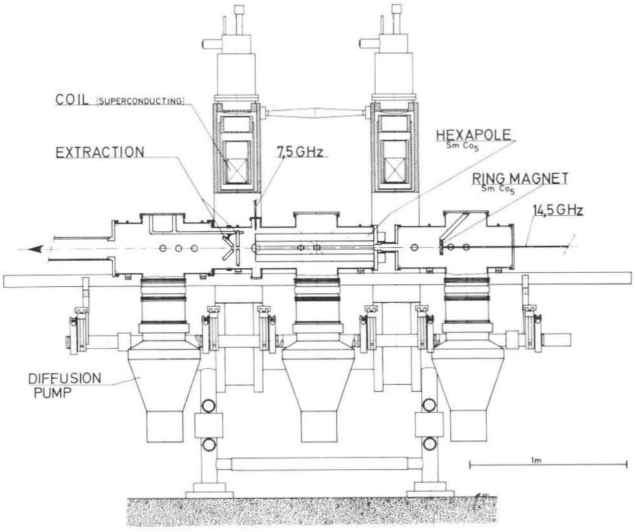

Fig. 1: HISKA, present state of design. The first stage is operated at 14.5 GHz and at a magnetic field of 5.2 KG. This field is produced by a small permanent ring magnet made of Samarium Cobalt. This is a compact Mini source. In the second stage the 7.5 GHz microwaves are fed into a magnetic field configuration generated by two superconducting coils and a permanent hexapole ($SmCo_5$) inserted into the vacuum.

The source is pumped with special diffusion pumps with negligible oil backstreaming.

The microwaves at 14.5 GHz, which corresponds to the 5.2 KG field, are fed in axially through a teflon window into 10 mm bore of the ring magnet using a boron nitride plug in. With less than 100 W microwave power a plasma density of 10^{12} n/cm^3 could be produced.

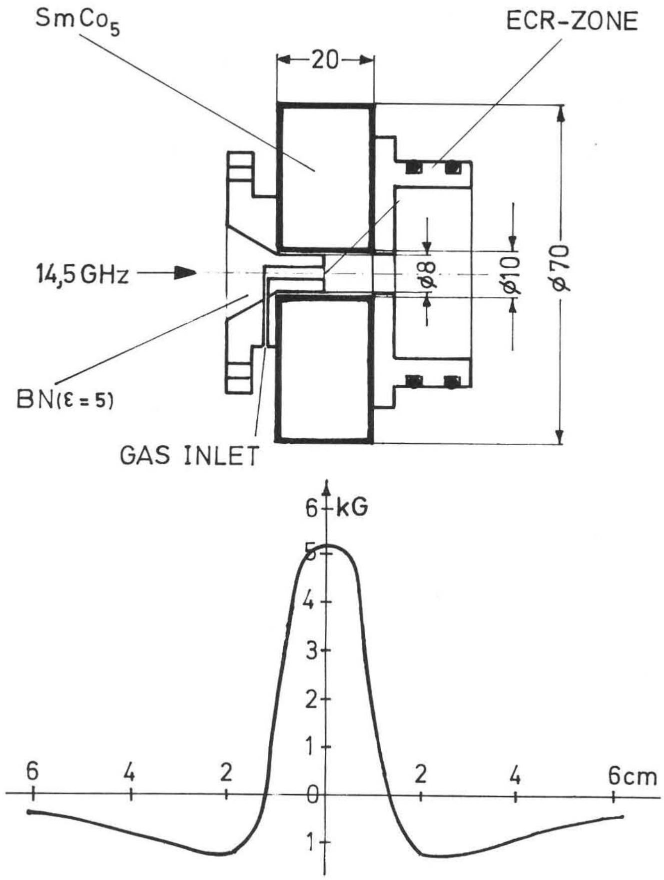

Fig. 2: The cross section of the Mini ECR-source in the first stage shows a permanent ring magnet with a central bore of 10 mm. In the middle of the bore an ECR plasma is produced at 5.2 KG with 14.5 GHz microwaves which are fed in axially through boron nitride. The axial field is shown below. With less than 100 W microwave power a plasma density of 10^{12} n/cm^3 was achieved.

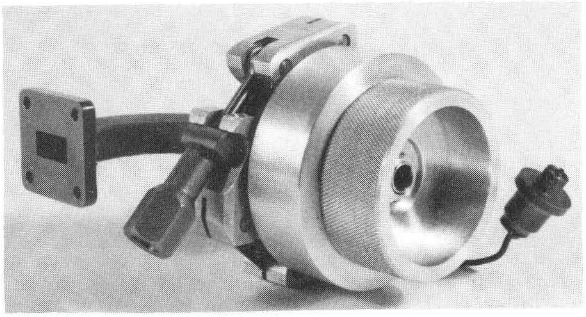

Fig. 3: Mini ECR-source

The vacuum is maintained by a 700 l/s diffusion pump with extremely low oil backstreaming. Figure 3 shows a photograph of the device.

In the second stage a magnetic bottle is generated by two Superconducting ring coils (fig. 4) and a permanent hexapole magnet (fig. 5). In order to get high pumping speed and good access to the second stage the ring coils are mounted in separate cryostats and the permanent hexapole is inserted into the vacuum chamber.

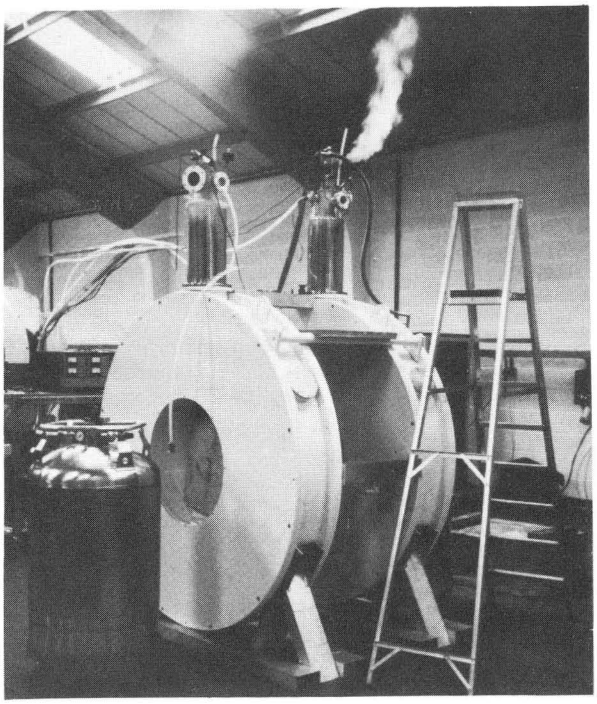

Fig. 4: The Superconducting ring coil on the test bench in the factory.

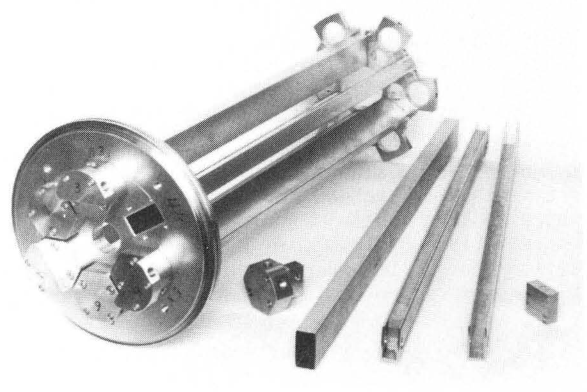

Fig. 5: The permanent hexapole mounted on a stainless steel flange. The six bars consist of SmCo$_5$-pieces pasted in U-profiles which are inserted into rectangular stainless steel tubes with integrated cooling channels. The whole device, which can be inserted into vacuum, is 70 cm in length, with 8 cm inner diameter and has a field strength of 4.2 KG on the surface of the poles. The open construction of the magnet gives good access for additional lateral pumping.

Each Superconducting coil has a warm bore of 70 cm, an outer diameter of 185 cm and an axial length of 30 cm. The maximum achievable field strength on the axis is 1.2 T. The distance between the coils can be changed from 80 cm to 120 cm in order to be able to vary the mirror ratio (fig. 6). At the end of August the Superconducting coils could be operated successfully in the persistant mode (leads removed) at 10.2 KG. The total boil-off rate for both cryostats was 5 l/h. Each helium vessel has a capacity of 60 l.

The permanent hexapole magnet consists of six separate bars of Samarium Cobalt ($SmCO_5$) to ensure proper superposition of the axial magnet field and the hexapolar field. Because the $SmCo_5$ has a porous structure it is not suitable for use under vacuum. Therefore the bars are inserted into rectangular stainless steel tubes with an integrated cooling system (fig. 7). To avoid corosion the cooling liquid is ethylene glycol instead of water. Each bar has a cross section of 43 x 17 mm and a length of 70 cm. The inner diameter of the hexapole is 8 cm and the field strength on the surface of the magnet is 4.2 KG.

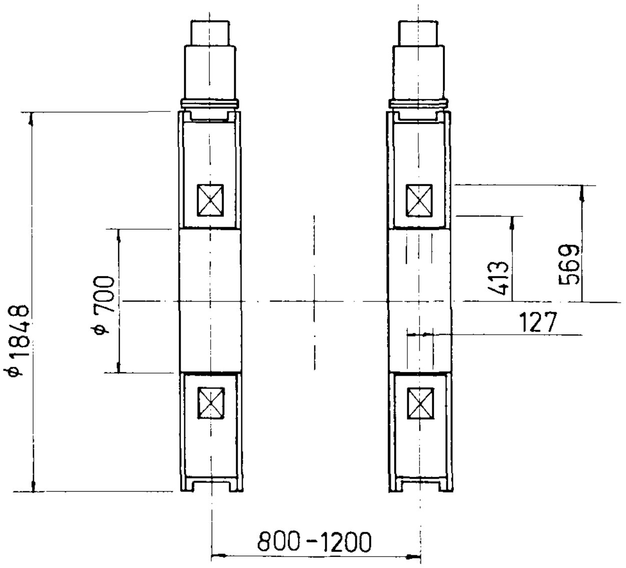

Fig. 6: The arrangement of Superconducting coils is shown schematically. The inner diameter of the warm bore is 70 cm and the outer diameter is 185 cm. The axial length of each coil is 30 cm. The distance between the coils can be changed from 80 cm to 120 cm in order to vary the mirror ratio of the field from 1.2 to 2.1. The maximum field on the axis is 1.2 T. The total helium consumption for both coils in persistant mode operation is 5 l/hr.

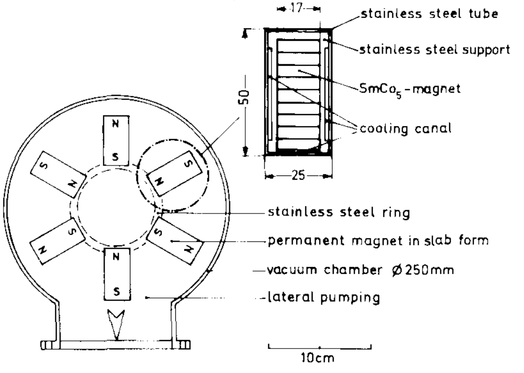

Fig. 7: Cross section of the permanent hexapole magnet inserted into the vacuum chamber. This arrangement allows for additional lateral pumping.

The open construction of the hexapole and the installation into the vacuum chamber allows for additional lateral pumping leading to the necessary high pumping speed in the second stage. The vacuum chamber is made of stainless steel and can be heated up to 300^{0} C. The pumping is done by a new type of diffusion pump with extremely low oil backstreaming; pumping rates are 1700 l/s for lateral pumping and 700 l/s in the extraction region. The expected vacuum pressure will be in the order of 10^{-8} mbar.

The microwave transmitter in the second stage operates at 7.5 GHz with a maximum rf power output of 5 KW. The microwaves are fed into the vacuum chamber radially through a quartz glass window.

The extraction system consists of a single electrode system with Pierce geometry. The extraction hole is 8 mm in diameter. The total source will be maintained at 10 kV, except the Superconducting coils and the diffusion pumps.

Since the new building for all external ion sources at the cyclotron was finished in May this year, the assembly of HISKA could be started. This work will end in October. Test runs are foreseen up to the end of this year. First operation at the cyclotron is expected to be in spring next year.

3. p-HISKA. - Concurrent with the work described above a 1:3 scale version of HISKA was built. The aim was to have an arrangement for testing plasma injection and transport, microwave handling, differential and lateral pumping, various extraction configurations and a Wienfilter for charge state distribution measurements. Encouraged by the exciting experimental results of the µ-MAFIOS source [4)] in 1979 it was decided to use the small scale version of HISKA not only as test facility but also as an ion source for the Karlsruhe cyclotron. This small source, called p-HISKA, was finished one year ago. Figure 8 is a schematic drawing of p-HISKA.

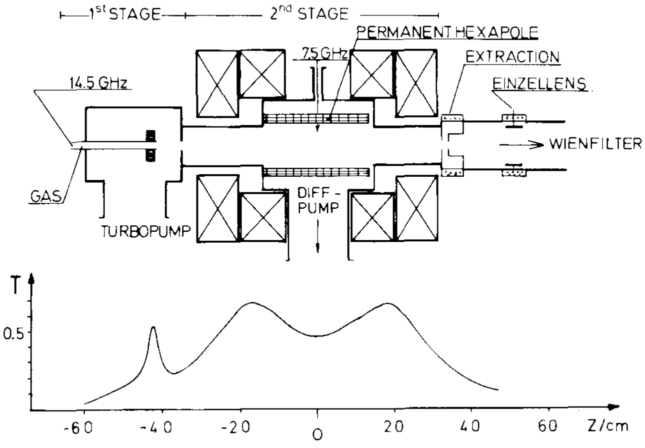

Fig. 8: Schematic cross section of p-HISKA. The first stage consists of a Mini ECR source operated at 14.5 GHz/5.2 KG and a differential pumping. The magnetic field configuration in the second stage is generated by two watercooled aluminium coils and a permanent hexapole magnet inside the vacuum chamber.
The axial field distribution is shown below.

The microwave frequency used in the first stage is 14.5 GHz; the corresponding magnetic field of 5.2 KG is produced by a small permanent ring magnet as described in section 2. The microwaves at 7.5 GHz in the second stage are fed in between the two coils generating the magnetic mirror field. These coils were made in the cyclotron workshop with anodized aluminum strip as conductor. The electrical insulation is due to the anodic aluminum oxide film which is grown on the surface by an electrochemical process. The current density is in the range of 10-12 A mm^{-2}. Because of the excellent heat conduction it is possible to cool with water only on the flat sides of the coil. Fig. 9 shows one part of the coil after winding. The maximum field is 3.9 KG at a mirror ratio of 1.7.

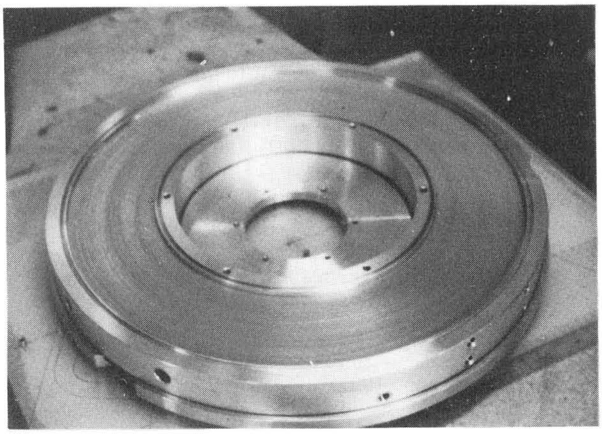

Fig. 9: One section of an aluminium coil after winding. The coil is made of anodized aluminium strip as conductor. The electrical insulation relies on a 5 µm thick anodic oxide coating. The current density is in the range of 10-12 A mm^{-2}. The good heat conduction necessitates cooling with water only on the flat sides of the coil.

The permanent hexapole magnet which is inserted into the vacuum chamber is of similar construction to that in HISKA but is only 280 mm in length (fig. 10). The pumping is done by a turbomolecular pump in the first stage and two diffusionpumps in the second stage. The total electrical power consumption of the source is about 80 kW. With p-HISKA it was possible to obtain the first ECR-produced fully stripped nitrogen ions outside Grenoble. The beam current for N^{7+} was about 25 nA. To measure the charge state distribution of the beam a Wienfilter is used. Fig. 11 shows a typical spectrum of nitrogen ions at 10 kV extraction voltage taken with an X-Y recorder after the Wienfilter.

In March 1981 p-HISKA was mounted onto the existing axial injection system at the cyclotron. In a first run the beam line and the cyclotron were optimized with a deuteron beam coming out of the ECR-source. Then the nitrogen was injected after setting the frequency of the cyclotron rf to the appropriate value. The accelerated and extracted N^{7+}- ions were detected by a semiconducting detector. In this way, the first fully stripped nitrogen ions produced in an ECR source and accelerated by the Karlsruhe cyclotron were found. Because of matching problems and the poor vacuum conditions (7 x 10^{-6} mbar) along the 15 m injection line most of the N^{7+} ions were lost. It is planned to inject in August this year, again with p-HISKA using a new horizontal injection line. Fig. 12 shows a photograph of p-HISKA mounted onto the injection line of the cyclotron.

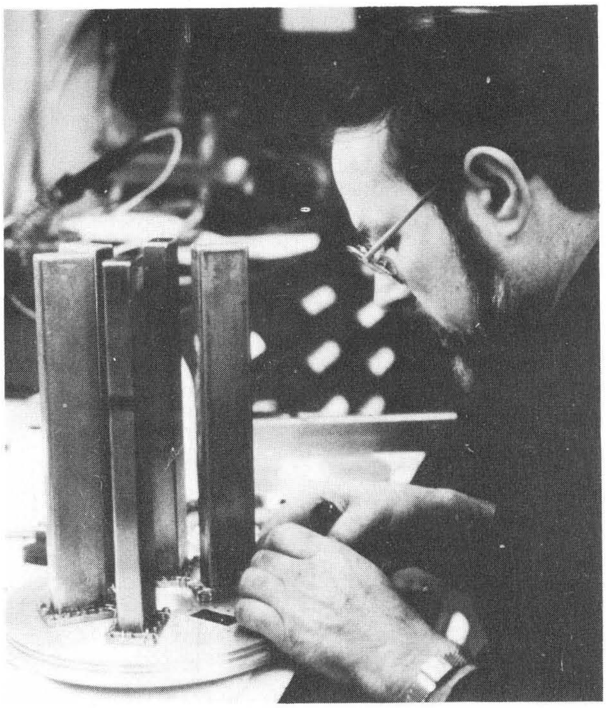

Fig. 10: Assembly of the permanent hexapole magnet for p-HISKA

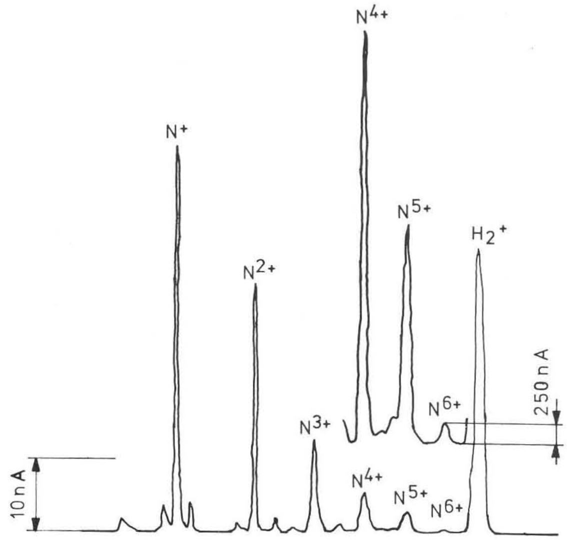

Fig. 11: Charge state distribution for Nitrogen ions from p-HISKA. Because they have the same e/m-value the fully stripped nitrogen ions cannot be discriminated from the H_2^+-ions. However, from results in Grenoble the relation N^{6+}/N^{7+} = 10 is known so that a current of about 25 nA N^{7+}-ions can be deduced.

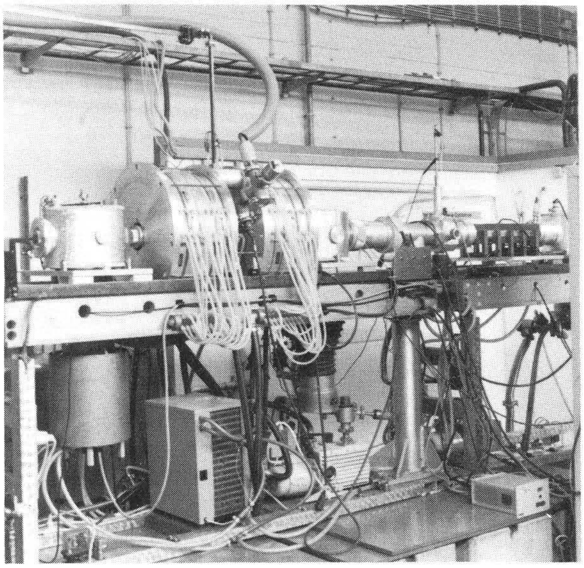

Fig. 12: Recent photo of p-HISKA.

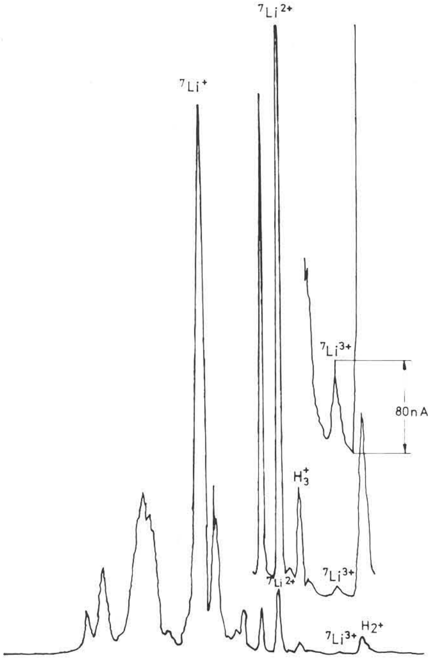

Fig. 13: Charged state distribution for lithium ions. In order to separate the fully stripped lithium ions from H_2^+ the isotope ^7Li was chosen. 80 nA of $^7Li^{3+}$-ions could be produced.

To investigate whether an ECR source is also able to deliver metal ions, p-HISKA was modified to produce Li-ions. For this purpose the first stage of p-HISKA was replaced by an Li-oven 1). Lithium is evaporated and diffuses into the second stage where it is ionized. The charge state distribution for ^7Li-ions is shown in Fig. 13. In a first experiment 80 nA $^7Li^{3+}$-ions could be produced.

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References

1) G. Haushahn, J. Möllenbeck, G. Schatz, F. Schulz, H. Schweickert, 7th Int. Conf. on Cyclotrons and their Applications, Zürich (1975) p. 376

2) V. Bechtold, D. Finken, L. Friedrich, G. Strassner, P. Ziegler, 7th Int. Conf. on Cyclotrons and their Applications, Zürich (1975) p. 390

3) R. Geller, 8th Int. Conf. on Cyclotrons and their Applications, Bloomington USA (1978) p. 2120

4) R. Geller, B. Jacquot, R. Pauthenet, Revue Phys. Appl. 15 (1980) p. 995