Characteristics of the injected ion beam in the ECR charge breeder $1^+ \rightarrow n^+$

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Characteristics of the injected ion beam in the E.C.R. charge breeder 1+ → n+

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Abstract:

Different ion species (rare gases, alkali, metallic) have been injected on the axis of the MINIMAFIOS - 10 GHz - Electron Cyclotron Resonance Ion Source which is the basics of the 1+ → n+ method, special attention have been paid to the optics of the incoming beam for the validation of the 1+ → n+ method for the SPIRAL project (Radioactive Ion Beam facility). The capture of the incoming ion beam by the ECR plasma depends, first, on the relative energy of the incoming ions with respect to the average ion energy in the plasma, and secondly, on the optics of the injection line.

The efficiency of the process when varying the potential V_{n+} of the MINIMAFIOS source with respect to the potential V_{1+} applied to the 1+ source ($\Delta V = V_{n+} - V_{1+}$) is an image of the energy dispersion of the 1+ beam.

1+ → n+ spectra efficiencies, ΔV efficiency dependence for the most efficient charge state obtained, and measured primary beam emittances are given for the Ar, Cr, Pb, S. Highest efficiencies obtained are respectively $Ar^{1+} \rightarrow Ar^{8+}$: 8.7 %, $Rb^{1+} \rightarrow Rb^{15+}$: 5.5 %, $Pb^{1+} \rightarrow Pb^{22+}$: 4.8 % , $Cr^{1+} \rightarrow Cr^{12+}$: 3.5 %.

Last results obtained are given for Sulfur.

1. Introduction

The conception of Radioactive Ion Beam facilities is a great challenge for the future of nuclear physics [1]. Many projects are undertaken all over the world. The main goal of these facilities is to provide to physicists the highest intensities of radioactive nuclei at high energies. For this purpose a very efficient and fast – due to the lifetime of the heavy species – charge breeder is required. The 1+ → n+ using an ECRIS [2] is one of the promising method fulfilling these requirements for c.w. operation, when the 1+ → n+ ECRIT is suitable for pulsed modes [3]. The efficiency of these methods has been already extensively proved with the n+ MINIMAFIOS source. The aim of this work is mainly to characterize, when obtaining the best efficiency yields, the optics of the 1+ incoming beams. These studies have been performed in collaboration with GANIL – SPIRAL.

2. The 1+ → n+ experiment

2.1 Aim of the process

When injecting a 1+ beam into the MINIMAFIOS source, the aim of the process is to obtain, in the shortest time, the best efficiency yield on a specific n+ extracted charge state.

2.2 Experimental setup

A new diagnostic chamber has been setup in the 1+ injection line [fig. 1]. The emittancemeter is composed by

- two motorized slits in the vertical and horizontal planes placed just before the image focal plane of the 90 deg. mass spectrometer
- at a distance of 270 mm of the slits the profile of the beam is measured by collecting the ion current on two orthogonal planes of 47 wires. The distance between two wires is 1 mm.

The potential of the n+ source can be varied with respect to the potential of the 1+ source, the difference is : $\Delta V = V_{n+} - V_{1+}$.

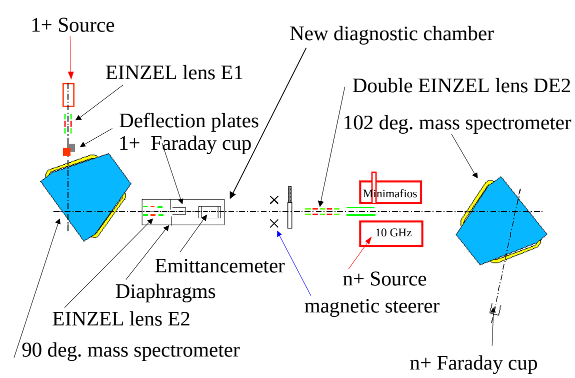

Fig. 1: 1+ → n+ experimental setup.

3. Efficiency yield versus ΔV

3.1 Results for Ar, Cr, Pb, Rb, S

The best results obtained for the 1+ → n+ process are recalled Table 1.

1+ Element	Optimized charge	Efficiency yield
Ar	8+	9 %
Cr	12+	3.5 %
Pb	22+	4.5 %
Rb	15+	5.5 %
S	7+	2.5 %

Table 1: Best efficiencies for the 1+ → n+ process.

When we vary the Δv value between the 1+ and the n+ source, we observe a variation of the efficiency of the 1+ → n+ process [4],[5]. The relative efficiency for different elements, as shown Fig.2, depends on the type of ion we want to be captured by the n+ plasma.

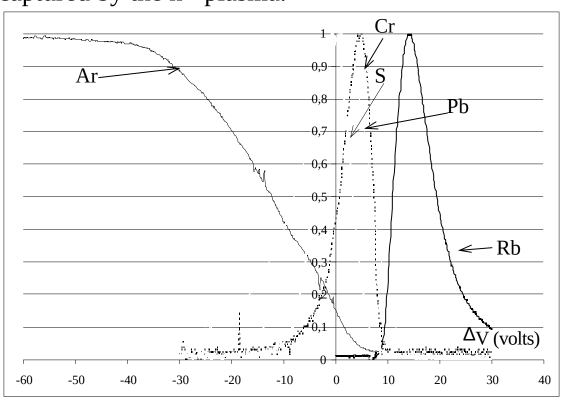

Fig. 2 : Relative 1+ → n+ efficiency versus ΔV.

3.2 The ΔV and the 1+ energy spread

In the case of metallic ions, the 1+ beam is directly captured by the n+ plasma, the process is not disturbed by any collision on the walls. Therefore to optimize the process, one has to tune the optics and to take care of the characteristics of the 1+ beam. We measured the relative efficiency of the process for two pressures in the 1+ source. As in many ion sources, the pressure inside the plasma chamber is not measured, but we increased the pressure near the gas inlet by a factor of 2 (8×10^{-5} to 1.6×10^{-4}). We clearly observe [Fig. 3] a change in the width of the curves. Due to the increased pressure, the energy spread of the extracted ions increases too. Therefore the width of the curves is an image of the energy spread of the 1+ incoming beam which is a fundamental parameter to obtain the highest efficiency possible. This must be considered when defining a 1+ source.

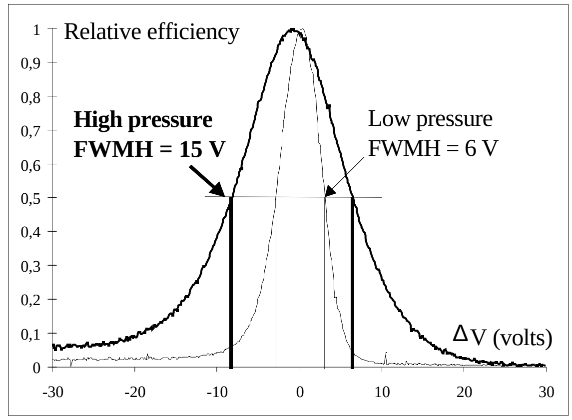

Fig. 3 : Increase of the FWMH with the pressure

4. Optics of the 1+ beam

4.1 Generalities

The 1+ → n+ method has to be evaluated with regard to a real configuration of a RIB accelerator, it has been done in the context of SPIRAL-GANIL. The fundamental parameter is the acceptance of the method. The methodology retained is the following: for rare gases and metallic ions the best yields are tuned without any diaphragm in the line, then the emittance of the beam is measured. Then a diaphragm can be inserted in the 1+ line and an increase of the yield is observed. The measurement of the emittance gives the optical characteristics of the 1+ beam which leads to the best efficiency for the 1+ → n+ method.

4.2 Argon

When injecting 1600 nA Ar^{1+} without diaphragm the efficiency yield for $Ar^{1+} \rightarrow Ar^{8+}$ is 9 %. The geometric emittance in the horizontal plane is given Fig. 4, for the vertical plane see Fig. 5.

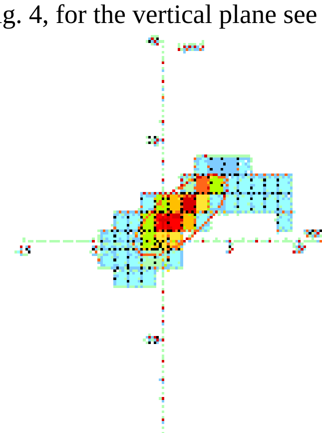

Fig. 4 : I=1600 nA, (0.87xI) in $\varepsilon_h = 20\ \pi$.mm.mrad

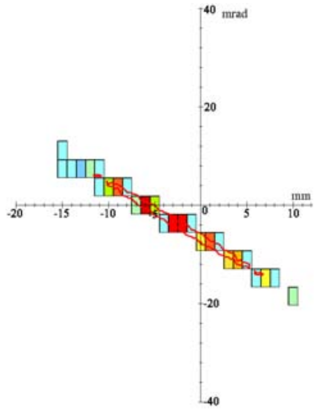

Fig. 5 : I=1600 nA, (0.89xI) in $\varepsilon_v = 14\,\pi$.mm.mrad

4.3 Chromium

When injecting 100 nA Cr^{1+} without diaphragm the efficiency yield for $Cr^{1+} \rightarrow Cr^{12+}$ is 1.5 %. The geometric emittance in the horizontal plane is given Fig. 6, for the vertical plane see Fig. 7.

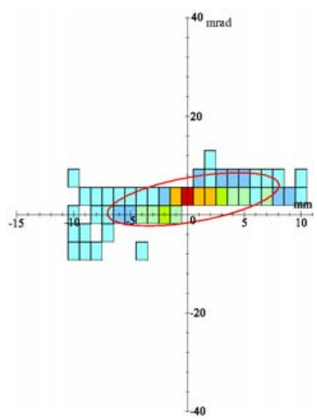

Fig. 6 : I=100 nA, (0.87xI) in $\varepsilon_h = 25\,\pi$.mm.mrad

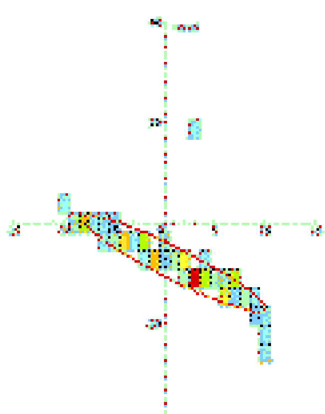

Fig. 7 : I=100 nA, (0.86xI) in $\varepsilon_v = 22\,\pi$.mm.mrad

When inserting a Φ12 mm diaphragm the Cr^{1+} reaches 50 nA and the efficiency yield for $Cr^{1+} \rightarrow Cr^{12+}$ is 2.1 %. The geometric emittance in the horizontal plane is given Fig. 8, for the vertical plane see Fig. 9.

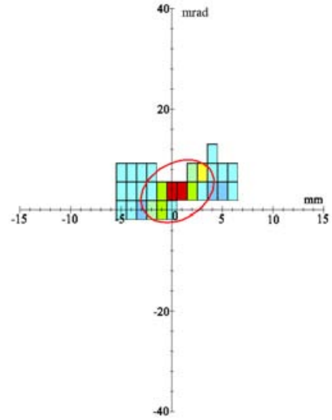

Fig. 8 : I=50 nA, (0.85xI) in $\varepsilon_h = 13\,\pi$.mm.mrad

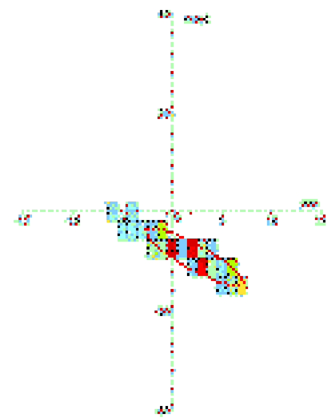

Fig. 9 : I=50 nA, (0.87xI) in $\varepsilon_v = 14\,\pi$.mm.mrad

When inserting a Φ8 mm diaphragm the Cr^{1+} reaches 32 nA and the efficiency yield for $Cr^{1+} \rightarrow Cr^{12+}$ is 2.9 %. The geometric emittance in the horizontal plane is given Fig. 10, for the vertical plane see Fig. 11.

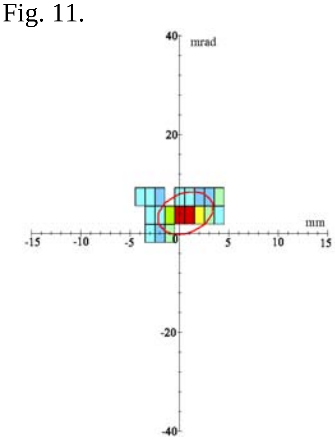

Fig. 10 : I=32 nA, (0.88xI) in $\varepsilon_h = 12\,\pi$.mm.mrad

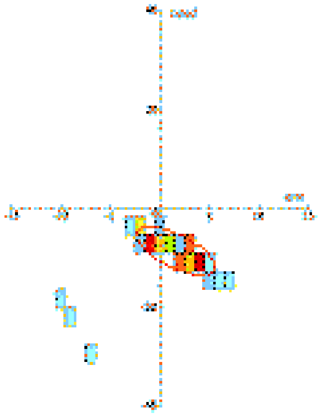

Fig. 11 : I=32 nA, (0.89xI) in $\varepsilon_v = 9\ \pi$.mm.mrad

4.4 Lead

When injecting 380 nA Pb^{3+} without diaphragm the efficiency yield for $Pb^{3+} \rightarrow Pb^{20+}$ is 2.7 %. The geometric emittance in the horizontal plane is given Fig. 12, for the vertical plane see Fig. 13.

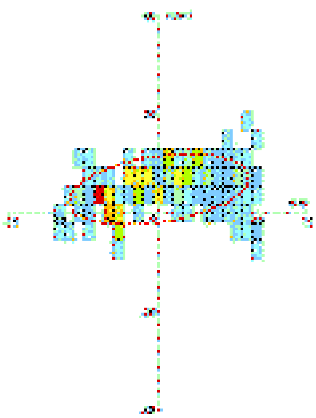

Fig. 12 : I=380 nA, (0.88xI) in $\varepsilon_h = 46\ \pi$.mm.mrad

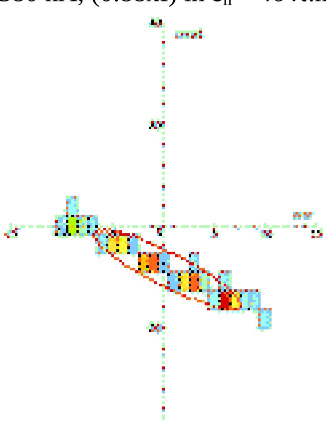

Fig. 13 : I=380 nA, (0.87xI) in $\varepsilon_v = 13\ \pi$.mm.mrad

4.5 Sulfur

A first experiment has been performed with sulfur. The 1+ beam has been produced in the NANOGAN source with SF_6. This first test has been done to prepare a Uranium experiment with UF_6 [6].

%. The geometric emittance in the horizontal plane is given Fig. 14.

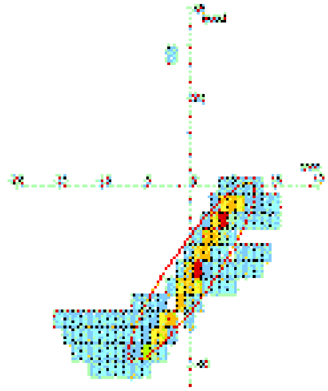

Fig. 14 : I=1300 nA, (0.87xI) in $\varepsilon_h = 46\ \pi$.mm.mrad

5. Conclusion

These experiments have shown the efficiency of the 1+ → n+ method, but a limitation in the acceptance. This limitation of the system has been identified, it is mainly due to the astigmatism of the 90 deg. spectrometer we used for these studies. The problem has been solved by correcting the angle of the poles with respect to the ion trajectories. A first test with argon has shown an increase in the acceptance of the system and a better efficiency yield : 10.4 % for $Ar^{1+} \rightarrow Ar^{8+}$ with $\varepsilon_h = 79\ \pi$.mm.mrad, which shows a better acceptance of the 1+ → n+ system.

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