Development of the RIKEN Atomic Beam Type Polarized Ion Source

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Abstract

The RIKEN atomic beam type polarized ion source has been assembled and is operational. The present level of performance is 140 μA with 50-60% polarization of the ideal value. Results from operation will be described.

I. INTRODUCTION

The RIKEN ring cyclotron can accelerate protons and deuterons up to 210 and 270 MeV, respectively. Use of a polarized beam will provide unique opportunities to study the spin dependent physics at intermediate energies. The program of constructing the polarized ion source started in 1990. Since we had little experience in this field, the decision was made to copy the reliably operating, modern and high-performance ion source. The one developed at TUNL[1] met our requirements and the fact that IUCF had started to construct its modified version, HIPIOS,[2] induced us to make the same choice as IUCF. We obtained a lot of helpful information both from TUNL and IUCF and also mechanical drawings from IUCF which allowed us rapid construction.[3,4]

The RIKEN polarized ion source of the atomic beam type is schematically shown in figure 1. It is very similar to HIPIOS of IUCF except that the beam traverses vertically. The assembling was completed in May 1992. The first acceleration test by the injector AVF cyclotron was performed in June, and by the ring cyclotron in October of the same year.

II. ION SOURCE

The ion source is placed about 8 m directly above the AVF cyclotron center. The ion source is mainly composed of a dissociator to generate an atomic beam which is well velocity-defined by a cold nozzel, a couple of almost identical sextupole magnet-rf transition units to create nuclear-polarized atoms through the hyperfine interaction, and a 2.45 GHz ECR ion source to ionize the nuclear-polarized atoms. A polarized beam is extracted by three electrodes, and focused through two einzel lenses. The spin direction of the polarized ion beam can be controlled by using the spin rotator which is installed at the exit of the ion source.

DISSOCIATOR

The performance of the dissociator was studied by using a compression tube installed downstream of the second sextupole magnet. A cooled atomic beam is formed by the copper nozzle with a 3 mm orifice. As the nozzle temperature T falls down, the flux of the atomic beam increases approximately in proportion to $1/T$ (figure 2). The intensity rapidly drops below 60 K because of the strong recombination at the copper nozzle. It is recovered by the known technique of forming a N_2 layer on the nozzle surface.[5)6)] N_2 is fed in near the nozzle through the MACOR support. The maximum beam flux into the 25 mm aperture is routinely observed to be 2.6 x 10^{16} atoms/sec.

The major difficulty we met is the short lifetime of the nozzle. During operation, the white powder, which was analyzed to be SiO_2, accumulates on the wall of nozzle. It reduces the beam intensity rapidly, *e.g.* down to 50% within a few hours, and sometimes plugs the nozzle orifice after a few days operation. This was remedied by making the nozzle longer, 28 mm to 61 mm, following the suggestion by Dr.

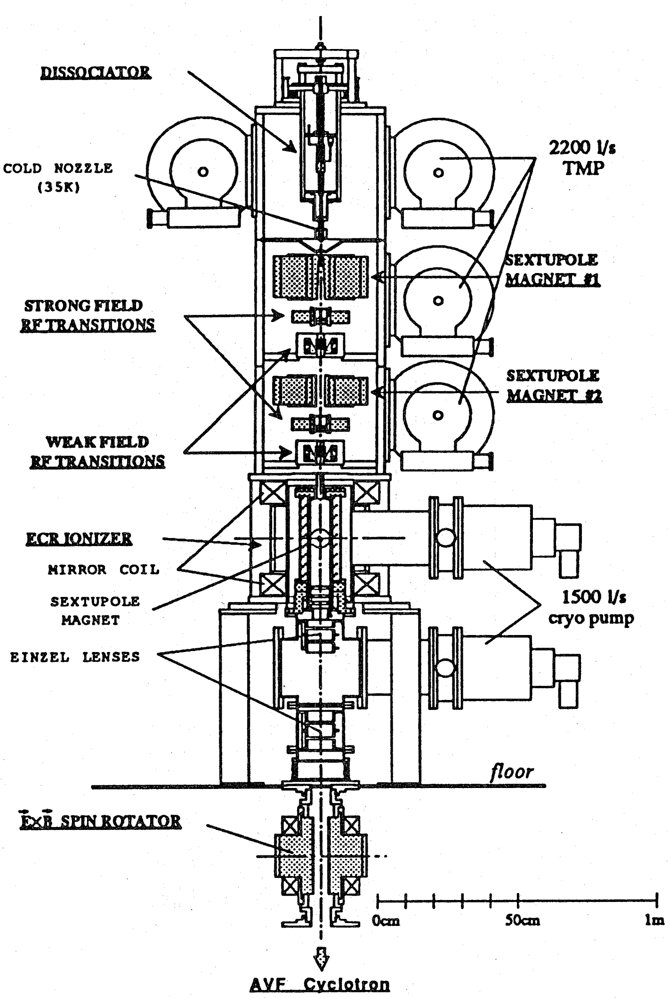

Fig. 1. Side view of the polarized ion source.

Schmeltzbach.[6] In this way the white deposits accumulate far away from the nozzle and the surface near the orifice will be kept clean. Another effective procedure is to keep the RF power as low as possible. As shown in figure 3a, the power of 60 W will be enough to obtain 90% of the saturated intensity. The currently best operating parameters are as follows: 20-30 scc/min D_2, 0.01 scc/min N_2, 37 K nozzle temperature and 60-80 W RF power with $\lesssim$ 3 W reflected. Under these conditions no reduction of intensity is observed for at least one week. It should be noted that we have never operated the ion source continuously for more than one week. The N_2-layer technique works very reliably.

SEXTUPOLE MAGNETS

The pole tips for the first magnet are linearly tapered along a 165 mm length of the sextupole providing axial beam entrance and exit apertures of 14 mm and 28 mm, respectively. For the second magnet the pole tips are machined to have a straight 30 mm inner aperture and a 115.5 mm length. The length of the first magnet was increased by 50% as recommended by TUNL.[3] Figure 3b shows the atomic beam intensity for various fields of the first sextupole magnet as a function of fields of the second sextupole magnet. The intensity does not pass the peak but seems to reach the plateau.

ECR IONIZER

The ECR ionizer is operated with the 2.45 GHz microwave, typically at a power of 30-40 W. The low magnetic field (87.5mT) which will reduce the proton polarization is not a problem since we are mainly interested in producing deuteron beams.

The early design of the ionizer also followed that of HIPIOS. The sextupole magnet consists of SmCo permanent magnets encapsulated in copper cans and was electrically isolated and biased to +7.5 kV operation voltage, while the vacuum chamber remained at the ground potential. The aperture of the extraction electrode was 1 cm in diameter. Good pumping was provided radially through the gap of the sextupole.

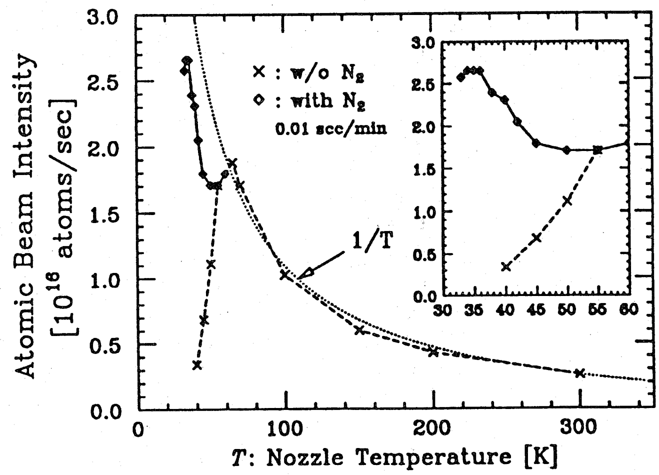

Fig.2. Dependence of atomic beam intensity on the nozzle temperature.

The problem that the ions were extracted axially to the upstream direction as well as radially through the gap of the sextupole magnet was immediately noticed. As a result the ions sputtered the RF transition units and the wall of vacuum chamber, inhibiting a long-term operation. We installed a mesh and an electrode to suppress the undesired extraction and the problem seemed to be settled. However, when the beam was injected into the cyclotron, we noticed that the suppressor was causing some instability to the ECR plasma. The best performance of the eary version of the ionizer was 20 μA with 60% polarization of the ideal value.[7]

We have modified the design of the ionizer close to the one at PSI.[6] A Pyrex plasma chamber is installed inside the sextupole magnet which is kept at the ground potentioal. The plasma region is pumped through the 5 cm aperture of three-stage extraction electrodes. The stable and long-term operation of the new ionizer allowed us extensive searches of optimum conditions. Currently the ion intensity of 140 μA is routinely observed.[7] The polarization, however, is reduced to 50% of the ideal value. We believe the low polarization is primarily

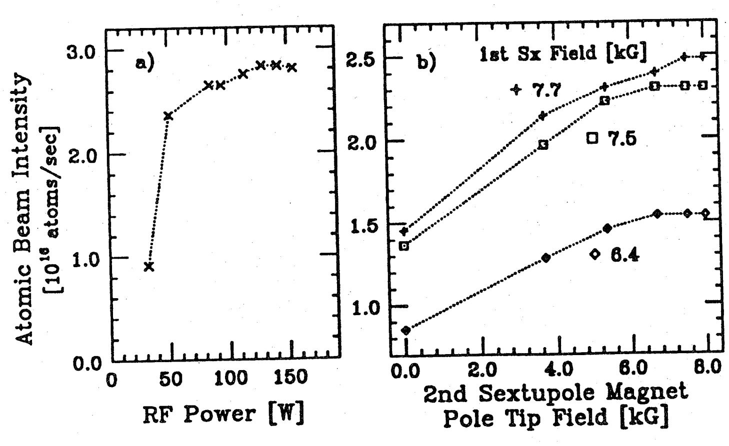

Fig. 3. Dependence of atomic beam intensity (a) on the dissociator RF power and (b) on the pole-tip field of the sextupole magnets.

due to insufficient pumping which causes an increase of the unpolarized background. We are installing a Ti sublimation pump and will continue to investigate the polarization reduction problem.

SPIN ROTATING SYSTEM

The polarization is measured at the exit of the AVF cyclotron (Ed = 14 MeV) by using the $^{12}C(d,p)^{13}C_{gnd}$ reaction and at the exit of the ring cyclotron (Ed = 270 MeV) by using the $d + p$ elastic scattering. The spin direction is freely controlled by using the Wien filter downstream of the ion source. Even if the beam is injected and accelerated with its spin axis inclined to the cyclotron magnetic field, a single turn extraction does not lead to a loss in the amplitude of polarization. According to this principle, we have succeeded in rotating the spin direction without reducing the polarization or the intensity. Fig. 4 shows polarization of P_x and P_y measured at the exit of the AVF cyclotron, firstly by varying the current, and secondly by varying the angle of the spin rotator. At the current of 55 A, P_y became zero, resulting in the fact that the spin direction was moved on the horizontal plane. Next, by varying the angle, for example, to 300 degrees, the spin was pointed towards the longitudinal direction on the horizontal plane. The polarization of P_x and P_y measured at the exit of the ring cyclotron (Ed = 270 MeV) is shown in figure 5. Keeping the current at 55 A, the spin was pointed, for example, towards both longitudinal directions on the horizontal plane by varying the angle to nearly 165 or 345 degrees.

III. CONCLUSION

Owing to the newly developed but well proven technology, the RIKEN polarized ion source has been successfully constructed and is reliably operating. The method of controlling the spin direction has been established incorporated with the acceleration technique. While we will still continue to try to improve the degree of polarization, the system is ready for experimental use.

IV. ACKNOWLEDGEMENT

We are very indebted to T.B. Clegg and the staff of HIPIOS who generously allowed us to copy their ion sources and provided us with helpful information. We are also grateful to P.A. Schmeltsbach for giving us valuable suggestions.

V. REFERENCES

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5) D. Singy *et al.*, Nucl. Instr. and Meth. B47 (1990) 167.
6) P.A. Schmeltzbach, private communication
7) The cited ion intensity is the difference between the beam current with sextupoles switched on and the one with sextupoles switched off. We do not directly cite the mass-analyzed current because that may include the current due to singly-charged molecule H_2^+ which will vary depending on vacuum conditions.

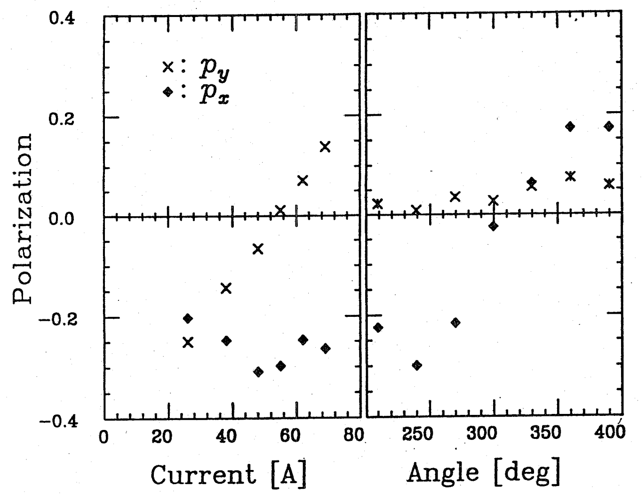

Fig.4. Polarization measured at the exit of the AVF cyclotron (Ed = 14 MeV) by using the $^{12}C(d,p)^{13}C_{gnd}$ reaction by varying the current and the angle of the spin rotator.

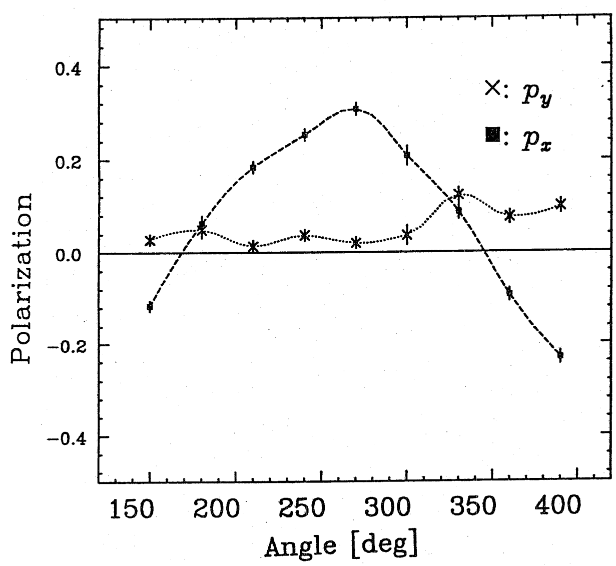

Fig.5. Polarization measured at the exit of the ring cyclotron (Ed = 270 MeV) by using the $d + p$ elastic scattering by varying the angle of the spin rotator.