Ion Optics of Optically Pumped Polarized H$^-$ Ion Source

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Abstract

An influence of the beam emittance and the polarization at the solenoidal magnet arround ionizer cell, where beam is ionized (H^0 → H$^-$), is studied by means of a beam optics calculation. The KEK OPPIS (Optically Pumped Polarized Ion Source) , which is upgraded at TRIUMF and will be installed at BNL, is used as a model of this paper. In this OPPIS, the sodium jet ionizer is used as a new instrument. We describe about the non-conservation of the beam emittance due to the multiple charge exchange between the proton or the H$^-$ and alkali ions, the depolarization by the fringing field of the solenoidal magnet, H$^-$ yields at this ionizer.

1 Introduction

At the first, we introduce the RHIC polarized H$^-$ ion source, so called BOPPIS (Brookhaven Optical Pumped Polarized Ion Source), which upgraded KEK OPPIS [1] and is being developed at TRIUMF [2].

A simple schematic of BOPPIS is shown by Fig.1. Polarized H$^-$ ion beam is produced by following method [1,2]: H$^+$ ions extracted from the ECR cavity enter the rubidium cell and capture polarized electrons from optically pumped rubidium vapor in a 2.5T magnetic field. As a result, they become hydrogen atoms having a polarized electron. Then, the hydrogen atoms pass through a Sona region where the polarization is transferred from electron spin to nuclear spin. The nuclear spin polarized hydrogen atoms capture an unpolarized electron from the sodium vapor in the sodium jet ionizer cell and become nuclear spin polarized H$^-$ ions.

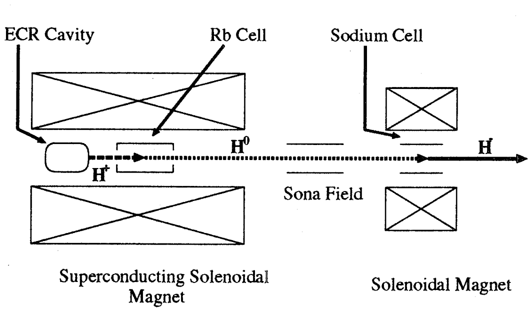

Fig. 1 Schematic of BOPPIS.

The H$^-$ ion beam extracted from the sodium jet ionizer cell is influenced by the fringing field of the solenoidal magnet surrounding Na. On the other hand, the incident beam is not affected by the fringing field, because of the beam is in a neutral charge state. Moreover, since multiple charge exchange processes between the beam and the sodium vapor occur, the beam emittance cannot be conserved. In spite of its importance, it is impossible to calculate the ion optics of the Na cell in a simple way. Therefore, we carried out a detailed ion optics calculation in this region. Our operation is consentrated to 4 points on follows:

1. To estimate the H$^-$ yield (H^0 → H$^-$) at the exit of the sodium jet ionizer cell.
2. To investigate the beam profile (x,y) and the beam emittance (x,x') by the influence at the fringing field at the exit of the sodium jet ionizer cell.
3. To investigata a decrease of the polarization.
4. The optimization of beam line components is very important because the beam emittance at the exit of the BOPPIS dominates the direction later beam line design.

2 Calculational Method

We assume the following initial conditions for performing the ion optics calculation. H^0 atoms (number = 5000) originate 20 cm upstream from the center of the sodium jet ionizer cell (20cm × ϕ 2.0 cm). The incident H^0 beam emittance (± 10mm: circle)×(± 1mrad) , the almost parallel beam, is assumed and looks like the parallel beam. The H^0 atoms enter the sodium jet ionizer cell. We calculate the beam emittance and the beam profile 30 cm downstream of the sodium jet ionizer cell. We include the contribution of the sodium vapor density distribution. As boundary conditions, we assume that the total sodium vapor thickness is 10^{15} atoms/cm^2. And, we assume a Gaussian distribution for the sodium vapor density distribution and operate the sigma (σ) of the Gaussian distribution as a parameter.

We assume H^0 → H$^-$ and H$^-$ → H^0 as charge exchange processes between hydrogen and Na atoms, with cross sections of about 0.03 × 10^{-14} cm^2 and 0.30 × 10^{-14} cm^2, respectively. At the beam energy (3.5 keV) of BOPPIS , other charge exchange cross sections are some orders smaller than the cross sections of the above processes and are negligible for this calculation. Moreover, we carried out a calculation for the degradation of the nuclear spin polarization; it is to examine the influence of the present solenoidal magnetic field for the nuclear spin polarization of the hydrogen atom and ion. We assume that the nuclear spin polarization of incident H^0 atoms is 1.0.

The calculation program using a combination of the Runge Kutta method and the Monte Carlo method. The former is used for the particle tracking. When we calculate the particle tracking, components (r,z,B_r,B_z) are precisely calculated by the magnetic field calculation program [OPERA2D] are used as the space mesh of the Runge Kutta calculation. Monte Carlo method is done for the charge exchange. Further details about the calculation of the charge exchange by means of the Monte Carlo method has already been published [3].

3 Results

We show the beam trajectory along the solenoid axis. Figure 2 shows the calculated results of the beam trajectory, Z=0 is the center of the sodium vapor cell (length = 20.0 cm). In the figure 2(a), thick and thin solid line show the magnetic field distribution and the sodium vapor density distribution with the Gaussian (σ=5.0cm), respectively. Figures 2(b) and 2(c) are H^0 and H^- trajectory of the transverse X projection, respectively, where the number of 100 particles is traced. It is clearly seen that H^- ion diverge from Z axis at the fringing field of the solenoidal magnetic field. On the other hand, many of H^0 atoms pass straight through the sodium jet ionizer cell. The point of charge exchange of $H^0 \rightarrow H^-$ or $H^- \rightarrow H^0$ is plotted in figures 2(d). The yield of H^- was 9.0%.

Figure 3 shows the degradation of the number the nuclear spin polarization over the fright of the solenoidal magnet. Since B_r at the fringing field is relative large, the reduction of the nuclear spin polarization especially occur. As a result, the nuclear spin polarization is 94∼100 at the 30 cm point toward downstream of the sodium jet ionizer cell.

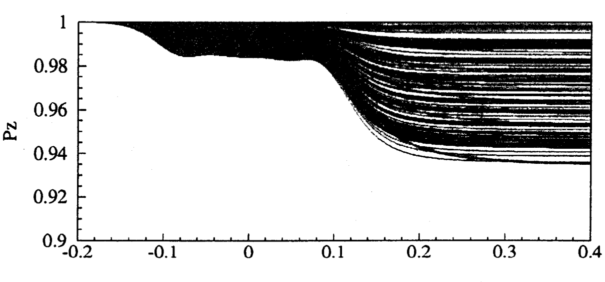

Fig. 3 The motion of spin polarization.

In the previous paragraph, we saw that H^- ions are diverging by the fringing field of the solenoidal magnetic field. As the next step, it is informative to see the beam at the final point (30 cm point toward downstream of the sodium jet ionizer cell). The beam profile (x,y) and the beam emittance (x,x') are shown by figure 4. The beam profile (x,y) and the beam emittance (x,x') are shown by the figures 4(a)-(b) and 4(c)-(d), respectively. The figures on left (a) and (c) are for H^0 and those on the right (b) and (d) are for H^-. It seems that the beams of H^0 and H^- are clearly separated. . The shape of the beam profile and emittance is diffused due to the multiple charge exchange [3]. In this case, a number of diffused H^0 are less than 10% of particles (about 4500) of the center region. The beam radius and the normalized beam emittance for the H^- ion are about 13 mm and 2.4 π mm mrad, respectively. We regard the normalized beam emittance as an 100% area of an ellipse on the phase space coordinate. Since the beam radius of the beam experienced the flight of the drift space (60 cm) is 10.6 mm in this case,the divergence with respect to the influence of the fringing field effect is about 2.4 mm. For an idea to optimize BOPPIS and to reduce the beam emittance, it is raised to shift an accelerate gap located at the downstream of BOPPIS to the region of the fringing field of the solenoidal magnet [4].

4 Summary

The influence at arround the ionizer of the OPPIS was investigated by means of the simulation with Runge Kutta method and Monte Carlo method. The results are summarized in Table. 1. These results are very important because it is possible to calculate the high energy beam line of RHIC accelerator complex.

H^- yield[$H^0 \rightarrow H^-$] (%)	8.4∼9.2
Beam Radius (mm)	13
Normalized Beam Emittance (mm mrad)	2.4π
Spin Depolarization (%)	∼6

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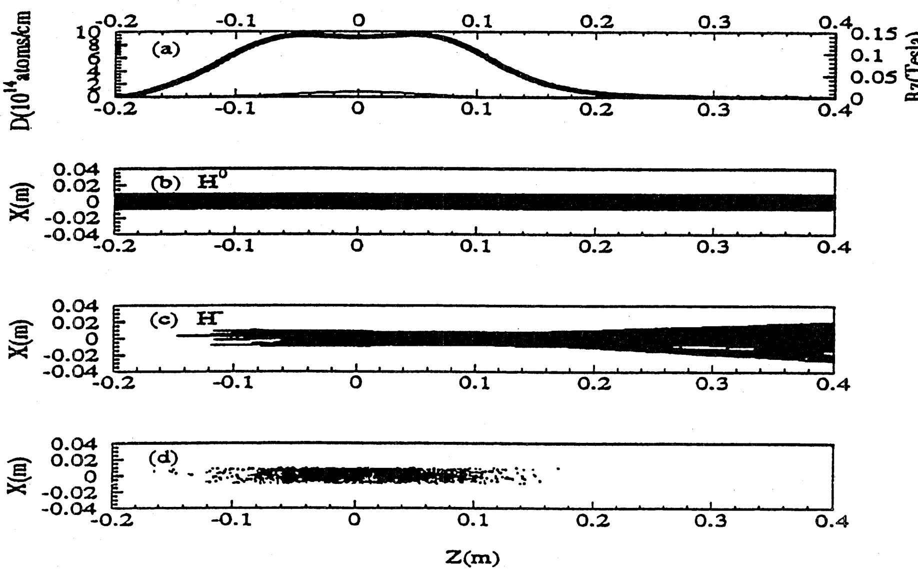

Fig. 2 The solenoidal magnetic field distribution, the sodium vapor density distribution, the H^0 and H^- beam trajectory, and charge exchange points.

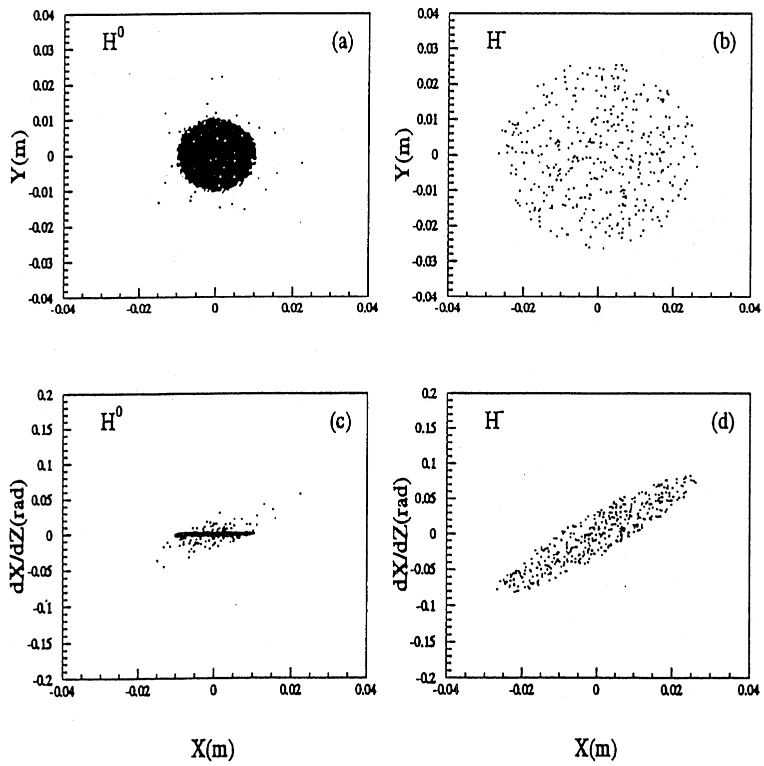

Fig. 4 The beam profile (x,y) and the beam emittance (x,x').