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KEK POLARIZED BEAM PROJECT AND POLARIZED ION SOURCE

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ABSTRACT

A new type polarized H^- ion source, which utilizes the charge-exchange reactions between fast H^+ ion beam and electron-spin polarized Na atoms, has been developed. Electron-spin polarized Na atoms were produced by optical pumping with using a dye laser tuned D_1 line of Na. We have obtained polarized H^- ion beam of 4 μA and 30 % polarization.

INTRODUCTION

There has been an interest in the acceleration of polarized protons in the KEK 12 GeV synchrotron from the beginning of the construction.$^{1)}$ The KEK 12 GeV synchrotron consists of four accelerator-stages 750 keV Cockcroft Walton preinjector, 20 MeV linac, 500 MeV booster synchrotron and 12 GeV main ring.

In order to accelerate polarized protons in this machine, it is, first of all, necessary to overcome a depolarization resonance in the booster synchrotron, which is very strong resonance at the energy of 239.3 MeV (γres. = 1.2552). Previously, it was thought that this resonance was so strong that it was impossible to accelerate polarized protons in the KEK machine.$^{2)}$ Recently, however, this depolarization resonance was re-estimated with a new concept of spin-flip and it was found that a proton spin was completely flipped and polarization was never destroyed as shown in Fig. 1. Thus, the acceleration of polarized protons in the KEK machine becomes possible to be realized. The strength of depolarization resonances in the main ring has been also calculated vigorously. In this way, the project for acceleration of polarized protons in KEK was started last year and a new 750 keV preinjector for polarized ion source is under construction.

It is well known that for a proton synchrotron H^- ions are more advantageous than H^+ ions because of the possilble use of the charge exchange multi-turn injection technique. In KEK, H^- injection scheme at the entrance of the booster is now being studied and some calcula-tions show that about 200 turns could be accepted and a half of them seems to be accelerated up to 500 MeV. The rest is lost by multiple scatterings in a carbon foil. This means that H^- ion beam from H^- ion source is apparently comparable with about 20 times intense H^+ ion beam from H^+ ion soruce. Thus, we have developed polarized H^- ion source so far. Previously, we have developed a Lamb-shift type polarized H^- ion source. However, because the space charge fields of charged particles quench the metastable atoms, it seems to be impossible to get a beam intensity of more than 1 μA.$^{3)}$

Since last year, we have started to develope a new type polarized ion source which utilized the charge-exchange reactions between a fast proton beam and electron-spin oriented Na atoms.$^{4)}$

The principle of this poalrized ion source is shown in Fig. 2. We named this polarized ion source, APOLON (Advanced POLarized ion source with Orintented Na atoms). There are two ways of producing electron-spin oriented Na atoms; inhomogeneous magnetic field scheme with multi-pole magnets$^{5)}$ and an optical pumping scheme by a dye laser beam.[6)] We have tested each scheme and found that the latter was superior for some reasons; the structure of the source is simple and beam intensity could be increases because the density of oriented Na atoms is high. We will describe performance of our present apparatus of APOLON prototype and some experimental results in the following.

APPARATUS AND EXPERIMENTS

A schematic set-up of APOLON prototype is shown in Fig. 3. H^+ ion beam was extracted from a pulsed duoplasmatron ion source. Pulse duration and repetition rate were 150 μsec and 20 pps, respectively. A potential of 20 — 25 kV was applied to the extraction electrode.

Optical pumping region contains a Na cell and oven. The cell was made of copper and placed inside the solenoid which produced a longtudinal magnetic field of 5 kG maximum. A sheath heater wound around the cell and heated to about 400°C prevents the Na atoms from depositing on the cell wall. Freon cooled traps placed at the entrance and the exit of the cell prevent the Na atoms form escaping.

Electron-spin oriented Na atoms were produced by a dye laser with R6G tuned on Na D1 line. The line width of the axial modes of the dye laser was about 30 ∿ 40 GHz with an output power of 1W. Electron-spin polarization was measured by a 6-pole magnet. A small fraction of oriented Na atoms was streamed through a 6-pole magnet and detected by a surface ionization detector. The current from the detector was varied by rotating a quarter wave plate which changes the vertical polarized light emitted by the dye laser to a circular polarized light. Electron-spin polarizaton can be estimated by the following equation, using the maximum ion current, Imax, and the minimum ion current, Imin, detected by the surface ionization detector,

$$P = \frac{\varepsilon}{A} ,$$

where $\varepsilon = (\mathrm{Imax} - \mathrm{Imin})/(\mathrm{Imax} + \mathrm{Imin})$ and A is an analysing power of 6-pole magnet. Analysing power of 6-pole magnet was re-estimated by Monte-Carlo simulation including the dependance of magnetic moment strength on the magntic field and it was 0.47. Fig. 4 shows the dependance of electron-spin polarization of Na atoms as a function of target density in the cell. Target density was calculated from the H^- ion current using $H^+ \rightarrow H^\circ$ and $H^\circ \rightarrow H^-$ charge-exchange cross sections. Electron-spin polarizaton decreased abruptly when the Na target density exceeded $3 \sim 4 \times 10^{11}$ n/cm^3. Imprisonment of the resonance radiation limits the Na target density.

This polarized H^- ion source uses the diabatic transitions between the hyperfine substates of H° atom to transfer the electron-spin polarization to the proton-spin polarizaton. In this scheme, a proton-spin polarizaton depends on the gradient of the magnetic field near the zero-crossing point and it is well known as a Majorana depolarization which has been estimated by Ohlsen[7)] in the case of Lamb-shift type sources. We estimated these depolarizations for our scheme. Fig. 5 shows the calculated values of a proton-spin polarization of 5 keV H° atom moving at the distance of 1 cm aparting from the beam center at first stayed in a hyperfine substate of $m_J = + 1/2$ and $m_I = + 1/2$. It was found that the magnetic field gradient near the zero-crossing point should be less thatn 1.0 G/cm. Fig. 6 shows the dependance of the proton-spin polarization on the magnetic field decay length from strong field to weak field. The decay length should be more than 2 cm.

Ionizing region consists of ionizing cell and solenoid coils. About 80 % of H° atoms were converted to H^- ions.

We have obtained polarized H^- ion beam of 4 ∿ 5 μA. The fraction of background H^- ions generated by the charge-exchange reactions with residual gasses was about 10 %.

POLARIZATION ESTIMATION

This polarized H^- ion source utilizes the charge-exchange reaction between a fast H^+ ion beam and optically pumped Na atoms. This charge-exchange reaction shows a quasiresonant character of the process forming the n = 2 states H° atom in this energy region. The n = 2 states of H° atom contains 2S and 2P states. If a polarized electron is captured in the 2P state only, electron-spin polarization is destroyed by a spin-orbit coupling force. This depolarization effect can be calculated using wave functions of the substates of 2P state which were varied as a function of magnetic field strength.

The decreased polarization is obtained in the following equations.

$$P = (1 + \delta_1^2 + \delta_2^2)/3 \ ,$$

$$\delta_1 = (\xi - \frac{1}{3})/\sqrt{1 + \frac{2}{3}\xi + \xi^2}$$

$$\delta_2 = (\xi - \frac{1}{3})/\sqrt{1 - \frac{2}{3}\xi + \xi^2} \ ,$$

where $\xi = \mu_0 B/\Delta E$. ΔE is a fine structure energy splitting between $2P_{3/2}$ and $2P_{1/2}$ states. A broken curve appearec in Fig. 7 shows the values calculated from the above equation.

Fig. 8 shows the variations of the extracted poalrized H^- ion current as a function of the magnetic field strength. Beam current increased at first and above 1 kG, it decreases gradually because of the emittance blow-up. When the magnetic field strength is about 2 kG, the ideal proton-spin polarization is 45 % if the optical pumping is perfectly performed and the diabatic transitions with zero-crossing method are completely ocurred. However, the meausred electron-spin polairzation of Na atoms was about 75 % and about 10 % of a total H^- ion current was unpolarized H^- ion current, so that proton-spin polarizaton of the H^- ion beam from the present source could be estimated to be about 30 %.

REFERENCES

1) S. Suwa, Proc. of AIP Conf. "High Energy Physics with Polarized Beam and Polarized Targets", 1978, 325.

2) H. Sasaki, Proc. of the U.S.-Japan Seminar on High Energy Accelerator Science, 1973, 247.

3) Y. Mori et al., Nucl. Inst. Meth., <u>141</u> (1977) 383.

4) Y. Mori et al., to be published in Proc. of 1981 Particle Accelerator Conference, Washington.

5) G.J. Witteveeu, Nucl. Inst. Meth., 158 (1979) 57.

6) L.W. Auderson, Nucl. Inst. Meth., 167 (1979) 363.

7) G.G. Ohlsen, LASL report, LA-3949 (1968).

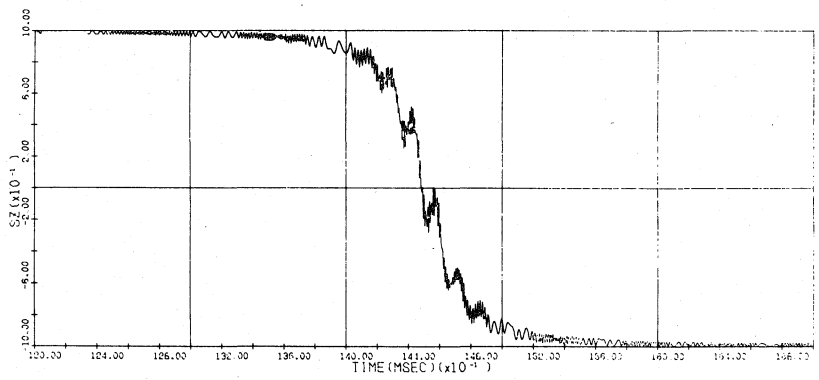


Fig. 1 Spin-flip at the resonance of booster synchrotron.

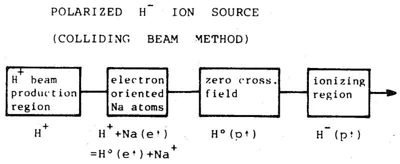
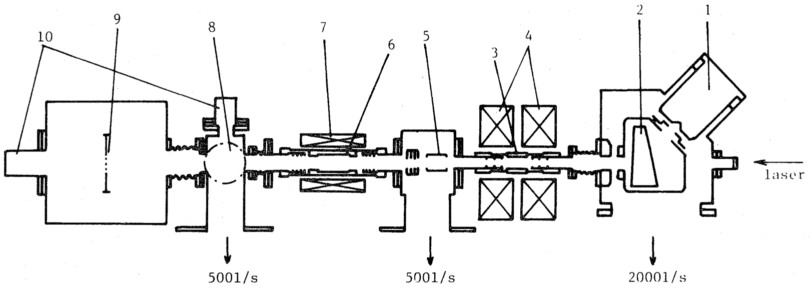


Fig. 2 Principle of APOLON.



1. duo plasmatron
2. 45° bend. magnet
3. Na optical pumping cell
4. solenoid coil
5. deflection plates
6. Na ionizing cell
7. solenoid coil
8. 90° analysing magnet
9. profile monitor
10. Faraday cup

Fig. 3 Schematic layout of APOLON.

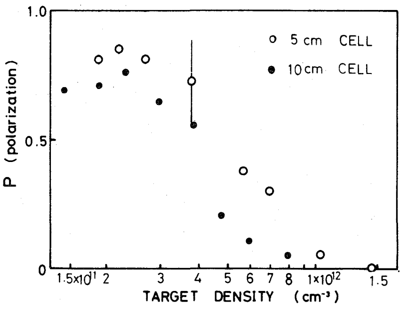
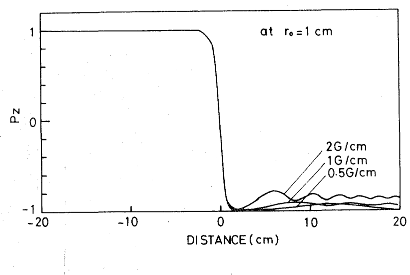


Fig. 4 Electron-spin polarization of Na atoms as a function of the target density.



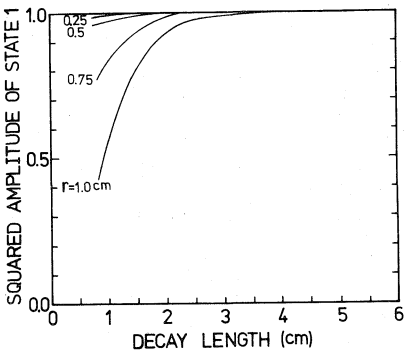
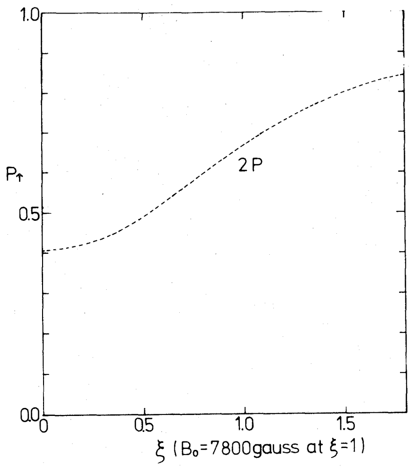


Fig. 6 Dependence of the proton-spin polarization on the magnetic field decay length.

Fig. 5 Diabatic transitions in zero-crossing magnetic field.



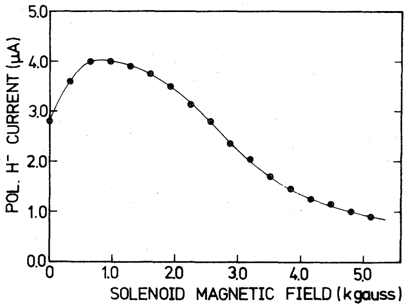


Fig. 7 Variations of the electron-spin polarization of H° atom as a function of the magnetic field strength.

Fig. 8 Variations of the extracted polarized H^- ion current as a function of the magnetic field strength.