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A NEW TYPE POLARIZED H^- ION SOURCE WITH ORIENTED Na ATOMS

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Introduction

The project of the acceleration of a polarized proton beam in the KEK 12 GeV synchrotron has been started in April 1980.[1,2] One of the keys to the success of this project is to develop an intense polarized H^- ion source. Because the use of the charge-exchange multi-turn injection technique is possible, polarized H^- ions are more adventageous than polarized H^+ ions in high energy synchrotron.

We have developed a prototype polarized H^- ion source based upon a new idea of utilizing the charge-exchange reaction between a fast proton beam and electron-spin oriented Na atoms. We named this polarized ion source, APOLON (Advanced POLarized source with Oriented Na atoms). The principle of this source is shown schematically in Fig. 1. This polarized source consists of four sections; a) H^+ ion beam production region, b) charge-exchange with oriented Na atoms, c) zero-crossing magnetic field region and d) ionizing region. There are two ways of producing electron-spin oriented Na atoms; an inhomogeneous magnetic field scheme with multi-pole magnets presented by Wittveen[3] and an optical pumping scheme by a dye laser beam proposed by Anderson.[4] We have already teasted each scheme [5,6] in order to determine which scheme is more useful and hopeful for increasing a polarized H^- ion current. We describe the characteristics and perfomance of Anderson's type polarized H^- ion source in this paper.

Apparatus and Experiments

A schematic set-up of APOLON prototype is shown in Fig. 2. Output polarized H^- ion beam current was measured by a Faraday cup at the exit of a 90° analysing magnet. A multi-wire profile monitor was placed at the distance of 60 cm aparting from the Na ionizing cell exit.

a) H^+ ion beam production region

H^+ ion beam was extracted from a pulse-operated duoplasmatron ion source. Pulse duration and repetion rate was 150 sec and 20 pps, respectively. A potential of 20–25 kV was applied to an extraction electrode. Extracted H^+ ion beam was analysed by a double focusing 45° bending magnet and after that, it was decelerated to 5 keV. H^+ ion beam current was about 8 mA just after decelerating, however, it decreased to less than 1 mA at the exit of the 90° analysing magnet.

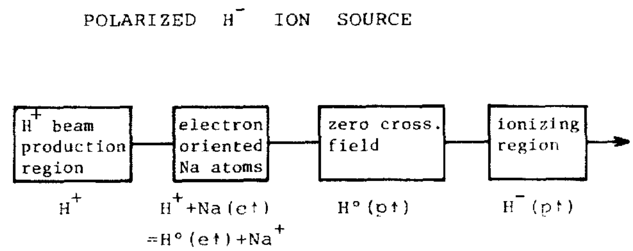
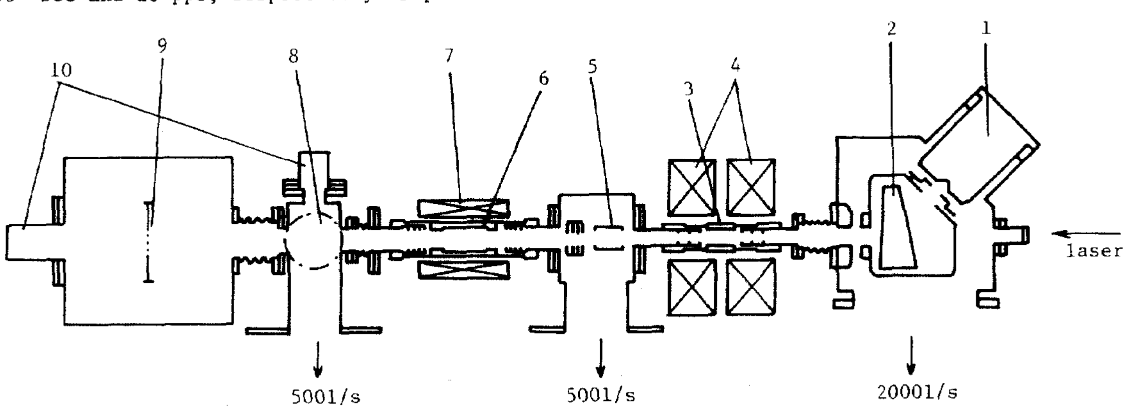


Fig. 1. Blockdiagram of polarized H^- ion source

b) Charge-exchange region with oriented Na atoms

Charge-exchange region contains a Na Cell and oven. Details of the cell and oven are illustrated in Fig. 3. The cell was made of copper and placed in the solenoid coils which produced a logitudinal magnetic field of 5 kG maximum. A sheath heater wound around the cell and heated to about 350°C-400°C prevents the Na atoms from depositing on the cell wall. Freon cooled traps placed at the enternce and the exit of the cell prevent the Na atoms from escaping.

Electron-spin oriented Na atoms were produced by a dye laser tuned on Na D_1 line. The line width of the axial modes of the dye laser was about 40 GHz at output power of 1 W. A quarter wave plate changed the vertical polarized light emitted by the dye laser to a circular polarized light. 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. From these measurements, polarization of optically pumped Na atoms could be estimated. About 75 % polarization was obtained for a Na target thickness of about 3 ∿ 5 × 10^{12} atoms·cm^{-2}.



1. duoplasmatron
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. 2. Schematic set up of APOLON prototype

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c) Zero-crossing magnetic field region

This polarized H^- ion source uses the diabatic transitions between the hyperfine substates of H^0 atom by the zero-crossing magnetic field to transfer an electron-spin polarization to a muclear (proton)-spin polarization. In this scheme, a nucler-spin polarization depends on the shape of the magnetic field near the zero-crossing point. Fig. 4 shows the variations of a proton polarization of 5 keV H^0 atom at first stayed in a hyperfine substate of $m_J = +1/2$ and $m_I = +1/2$ near the zero-crossing point. It was found that the magnetic field gradient near the zero-crossing point should be less than 1.0 G/cm.

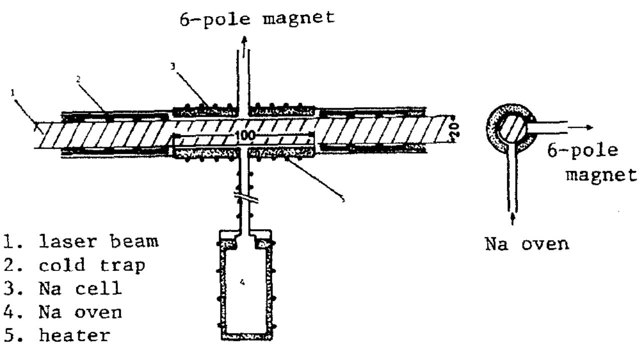

Fig. 3. Schematic View of charge-exchange cell and oven

d) Ionizing region

Ionizing region consists of ionizing cell and solenoid coils. Sheath heaters were wound around the cell and freon cold traps were placed at the entrance and the exit of the cell. About 7 ∿ 8 % of H^0 atoms were converted to H^- ions shown in Fig. 5 when the cell temperature was about 320°C.

We have obtained polarized H^- ion beam of 4 μA and a fraction of background H^- ions generated from the charge exchange reaction with a residual gass was about 10 %.

Fig. 6 shows the variations of polarized H^- ion beam current as a function of H^+ ion beam energy. We found that an optimum energy to get a maximum H^- ion current was 7 keV.

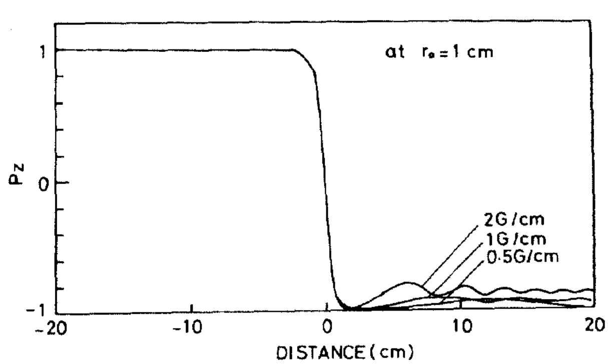

Fig. 4. Variations of a proton polarization of 5 keV H^0 atom near the zero-crossing point

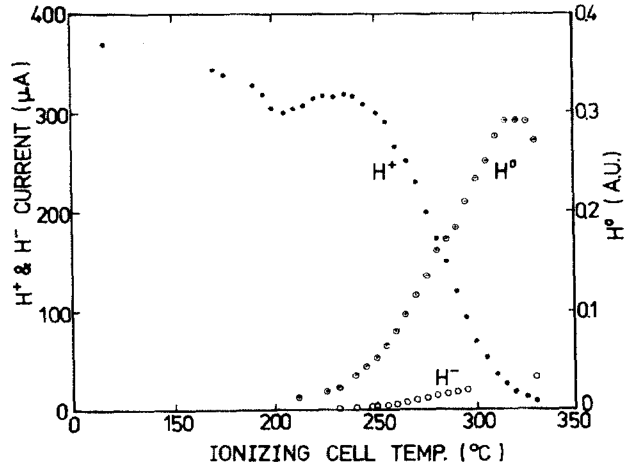

Fig. 5. Variations of H^+, H^- and H^0 intensities as a function of the ionizing cell temperature

Polarization Estimation

This polarized H^- ion source utilized the following charge-exchange reactions to obtain an electron-spin polarized H^0 atomic beam.

$$H^+ + Na(e\uparrow) \rightarrow H^0(e\uparrow) + Na^+$$

If a polarized electron of Na atom is captured in 1S state of hydrogen atom, electron-spin polarization is not destroyed after the reaction and ideally, a 100 % proton-spin polarization can be achieved by the zero-crossing magnetic field scheme. However, this charge-exchange reaction shows quasiresonant character of the process forming the n = 2 states H^0 atom in this energy region. The n = 2 states of H^0 atom contain 2S and 2P states. If a polarized electron enters in the 2P state only, the electron spin is depolarized by a spin-orbit coupling force and it is easy to calucurate the decreased electron-spin polarization as a function of the magnetic field strength, which is shown as a broken curved appeared in Fig. 7. About a quarter portion of H^0 atoms are formed in the 2S

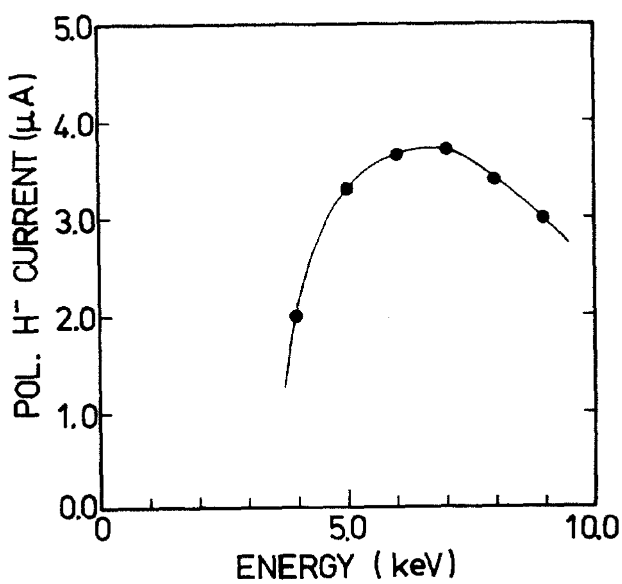

Fig. 6. Variation of the measured polarized H^- ion current as a function of H^+ beam energy.

state, so that the electron-spin polarization after the reaction varies with a solid curve as a function of the magnetic field strength as shown in Fig. 7. Fig. 8 shows the variations of the extracted polarized H^- ion current as a function of the magnetic field strength at the optical pumping cell. A maximum current was obtained near the magnetic field of about 1 kG. In this magnetic field stength, an ideal proton polarization is 52 % as shown in Fig. 7, if the electron-spin polarization of optically pumped Na atoms is 100 % and the diabatic transitions are completely occurred. The measured electron-spin polarization of Na atoms, however, was 75 % and about 10% of atotal H^- ion current was unpolarized background H^- ion current, so that the proton-spin polarization of the H^- ion beam from the present source was estimated to be about 30%.

Results

We have developed a new type polarized H^- ion source using a reaction between a fast proton beam and electron-spin oriented Na atoms, and obtained a 4 μA H^- beam current of about 30 % polarization. Polarization was estimated by the procedure described above. In order to increase the polarized H^- beam current it is necessary to extract much more intense H^+ beam from duoplasmatron ion source. Improvements of the extraction system are now progressing.

Proton polarization is considered to be rather low because a charge exchange reaction between a proton beam and Na atoms shows a quasiresonant character of the process forming the n = 2 states H^0 beam. However, proton polarization depends on the magnetic field strength of the charge exchange cell and H^+ beam energy. We plan to measure a proton polarization directly by means of a nuclear reaction.

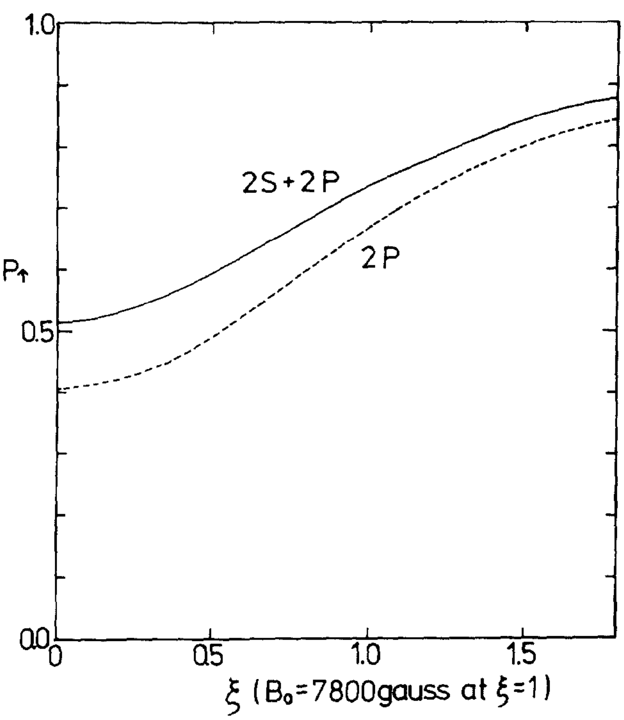

Fig. 7. Variations of the electron-spin polarization of H^0 atom as a function of the magnetic field strength

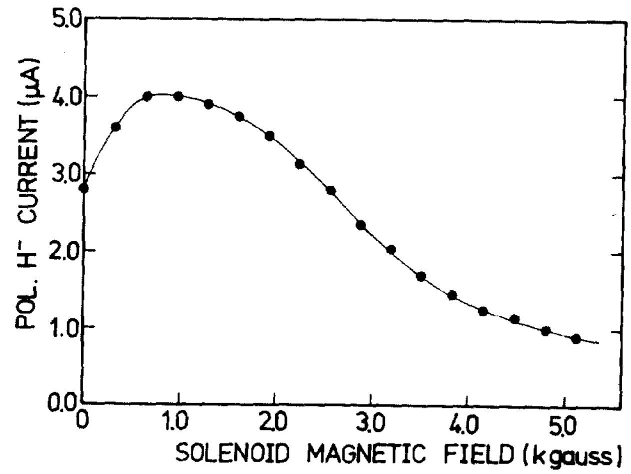

Fig. 8. Variations of the extracted polarized H^- ion current as a function of the magnetic field strength

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