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THE OPTICALLY PUMPED POLARIZED H^- ION SOURCE AT KEK

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ABSTRACT

Recent progress on the optically pumped polarized H^- ion source is described. Beam current of 50 μA with nuclear polarization of 56 ± 5 % has been obtained with an intense pulsed dye laser. Experimental results for radiation trapping are also described.

INTRODUCTION

The optically pumped polarized ion source has been developed at KEK for the 12-GeV proton synchrotron[1]. This source is based on the electron-capture reactions of H^+ ions with optically pumped electron polarized sodium atoms. In order to get a high beam current with high polarization, it is important to obtain a thick sodium target with high polarization. Until recently, the optically polarized H^- ion source at KEK used three cw dye lasers to produce ∿ 50 % polarization in sodium vapor of thickness ∿ 1×10^{14} × atoms/cm^2. The source is pulsed at a repetition rate of 20 Hz with a pulse width of ∿ 70 μs. If a pulsed dye laser were used at the ion source pulse rate, the very high peak intensity could possibly result in a sodium target polarization near 100 % during the ion source pulse[2]. With that in mind, we built a flashlamp-pumped pulsed dye laser, which can produce two orders of magnitude more peak power than cw lasers[3]. So far, we have obtained 50 μA H^- ion current with 56 ± 5 % polarization from the ion source using this pulsed dye laser.

Radiation trapping reduces the efficiency of optical pumping at high atomic densities. Recently, Tupa et al.[4] examined the effect of radiation trapping theoretically and proposed new rate equations for three-level optical pumping, having additional radiation trapping terms. In order to test their calculations we made measurements with the pulsed dye laser, which was sueful for these experiments because its high power saturated the polarization even at high atomic densities where radiation trapping occurred. The results of the experiments are in this paper.

STATUS AND OPERATION WITH THE PULSED DYE LASER

The schematic layout of the polarized ion source is shown in Fig. 1.

The pulsed dye laser uses two Xe flashlamps which pump R6G dissolved in ethanol flowing through a pyrex tube. The power supply uses a resonant charging circuit in the PFN. The wavelength of the laser light is tuned with a three-plate birefringent filter and a 1.1 mm thick coated etalon. The setup of the pulsed dye laser is shown in Fig. 2. The peak power output ranges from 500 - 700 W and the pulse width is 100 μsec. The laser bandwidth is about 28 GHz.

In order to measure the polarization of sodium atoms, a Faraday rotation technique[3-5-6] was used. A linearly polarized probe beam, passing through the sodium cell, underwent Faraday rotation in the presence of sodium vapor and also a further rotation if the sodium was polarized. The time-dependent Faraday rotation was detected as the variation in signal from a photo-multiplier, which detected the probe light transmitted by a linear polarizer. Figure 3 shows the photo-multiplier signal is flattopped, indicating that the polarization is saturated (at ∿ 100 % in this example). The measured sodium polarization as a function of the sodium atomic density, at a peak laser power of 370 W, is shown in Fig. 4. Above a density of ∿ 1×10^{13} atoms/cm^3 the polarization was usually still saturated at a level less than 100 %. This effect is well explained by radiation trapping and is described later. When three cw dye lasers were used to optically pump the sodium, the polarization at an atomic density of 1×10^{12} atoms/cm^3 was about 90 %, decreasing to 40 % at 5×10^{12} atoms/cm^3. As can be seen from Fig. 4, a polarization of 90 % at an atomic density of shows the polarized H^- ion current as a function of the sodium cell temperature, measured at an energy of 750 keV (open circles) after acceleration by the Cockcroft preaccelerator and the 40 MeV linac respectively. The polarization measured at 40 MeV by p-C reactions is also shown. The H^- ion beam current of 50 μA at a polarization of 56 ± 5 % was obtained at a cell temperature of 230°C. Raising the cell temperature to 245°C increased the H^- ion current to 180 μA, although the polarization decreased to 43 ± 5 %.

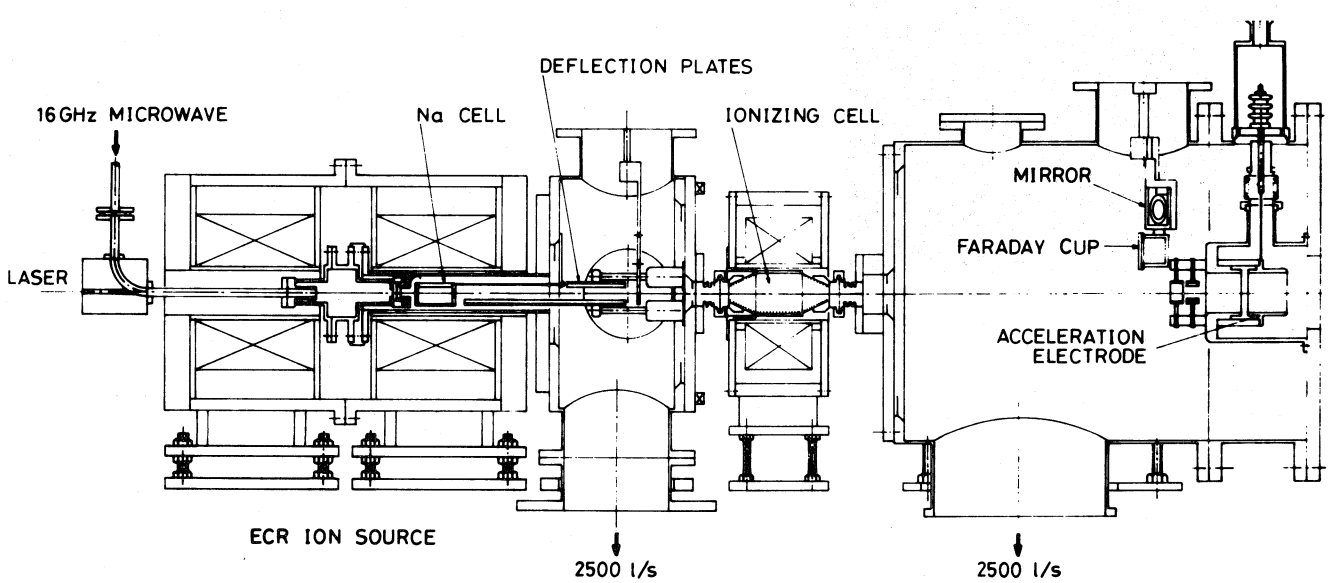
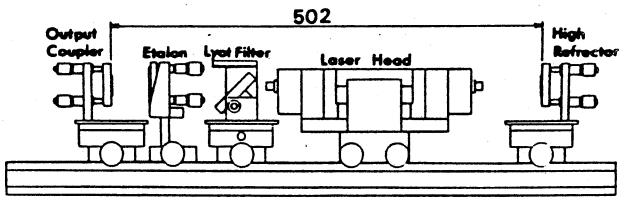


Fig. 1 Schematic layout of KEK optically pumped polarized ion source.



DYE LASER OSCILLATOR

Fig. 2 Setup of the pulsed dye laser.

RADIATION TRAPPING

Recently, Tupa et al. examined theoretically the effect of radiation trapping in optically pumped sodium vapor[4]. According to their calculations, the polarization of optically pumped sodium atoms in thick targets is affected to a large degree by radiation trapping.

The polarization of the sodium atoms calculated according to Tupa et al. is shown in Fig. 4 as a solid line. As can be seen, the experimental results show good agreement with the calculated curve.

An interesting characteristic of radiation trapping appears in the polarization relaxation process. In a thick target, photons emitted by excited atoms are usually re-absorbed by ground state atoms and are confined by the system. This leads to an increase in the proportion of excited atoms and affects ground state polarization relaxation. Therefore, at high densities two different polarization relaxation rates can be seen, one rapid rate due to excited state decay, and a slower rate due to wall collisions.

The calculated time-dependent polarization and the corresponding Faraday rotation signal derived from the polarization are shown in Fig. 6. In this calculation, we assumed a relaxation time due to wall collisions of 250 μs, a laser beam filling the cell volume, and a trapezoidel laser pulse shape. As can be seen, the calculated curves show two different polarization relaxation rates. In a preliminary experiment using silicon dry film coating on the sodium cell walls, we observed two different relaxation rates very similar to the calculated rates.

We have thus confirmed the validity of the assumptions used by Tupa et al. in their equations predicting the effects due to radiation trapping in alkali vapor cells. This will remove many uncertainties in the design of alkali vapor cells and in the polarization attainable.

CONCLUSION

Using an intense flashlamp-pumped pulsed dye laser, a polarized H^- ion beam of 50 μA with 56 ± 5 % nuclear polarization has been obtained from the optically pumped polarized ion source. At a higher sodium atomic density, a beam current of 180 μA with 43 ± 5 % polarization was achieved. The effect of radiation trapping was also measured at high atomic densities and the experimental results showed good agreement with calculations performed according to Tupa et al..

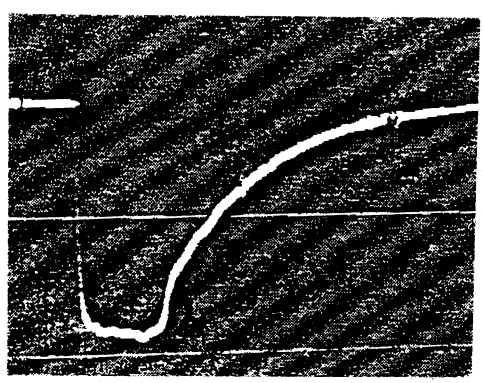


Fig. 3 Photomultiplier signal of Faraday rotation. H: 50 μs/div., V: 5 mV/div.

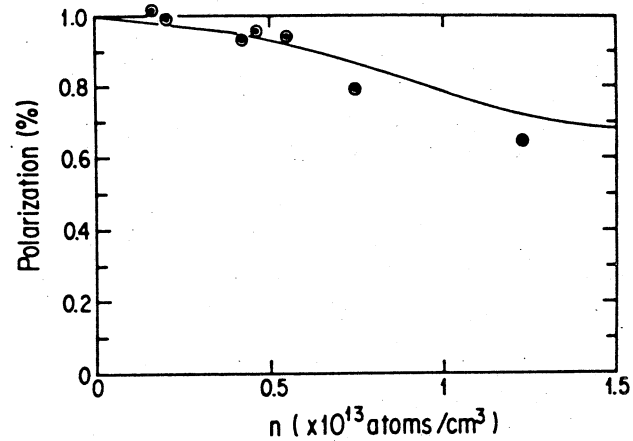


Fig. 4 Measured (circles) and calculated (solid line) polarization of the optically pumped sodium vapour.

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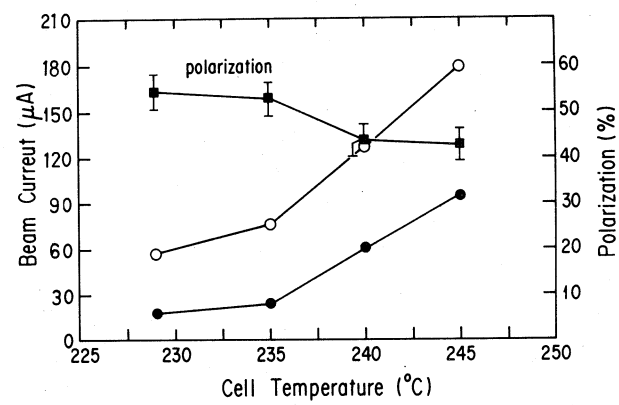

Fig. 5 Beam intensities and polarizations of the accelerated H^- beams. Open circles show the beam currents at 750 keV and closed ones the beam currents at 40 MeV, respectively.

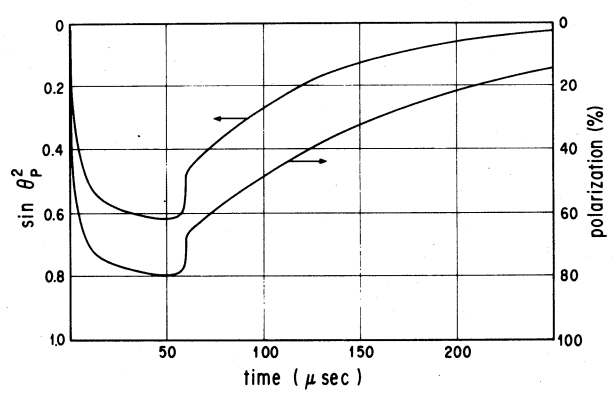

Fig. 6 Calculated time-dependent polarization (lower) and the corresponding Faraday rotation signal (upper).