Development of Polarized Radioactive Nuclear Beams II — Rb Polarization by Laser Optical Pumping —

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In the spin polarizer we propose for radioactive nuclear beams, the electron spin in Rb atom is polarized by laser optical pumping and the electron is transferred to the ionic states of the RI beam ion. Since the electron transfer cross section is estimated to be around 10^{-14} cm^2, it is essential to achieve high Rb polarization at the Rb density around 10^{14} atoms/cm^2. We have successfully tested the optical pumping in the test bench constructed for the feasibility test of this method. We report here the achievement of Rb polarization.

The Rb container is very similar to that designed by Tanaka *et al.* for the polarized ^{3}He ion-source at RCNP [1]: The Rb cell consists of two coaxial cylinders and the liquidized Rb is contained in the outer cylinder which serves as the reservoir for the Rb vapor at the saturated vapor pressure and the Rb vapor diffuses into the inner cylinder through thin slits (2 mm wide and 100 mm long) cut in the axial direction on the cylinder wall. The Rb temperature is controlled with an accuracy of ± 0.1°C by a heater wound on the outer cell and platinum thermometers set in the inner cell. The inner diameters of the outer and the inner cells are 34.5 mm and 18 mm, respectively. The Rb vapor is evacuated through holes (10 mmϕ) of the both ends of the inner cylinder and holes (10 mmϕ) of baffle disks placed 35 mm away from the both ends of the cell. The beam goes through these holes. The baffles are water-cooled and the major part of the evacuated Rb thus adheres to them. The vaccuum outside the baffles is kept to a few times 10^{-6} Torr, wheras that in the inner cell is more than two orders higher. The effective length of the cell is 165 mm. In the whole region of the cell a magnetic field is applied in the axial direction by a solenoid coil. Its magnetic field is inhomogeneous; at the ends of the cell the field strength is about 1/3 of that at the center. This inhomogeneity is helpful to reduce the depolarization due to the "radiation trapping".

The pumping laser beam is supplied from a Ti:Sapphire laser system (Spectra-Physics 3900S) excited by a diode laser (Spectra-Physics Millenia X; 532 nm, 10 W). The wavelength was tuned to 795 nm which corresponds to the D_1 transition of Rb atom. The line-width was adjusted to 5 GHz by using a thin etalon installed in the Ti:Sapphire laser in order to meet the inhomogeneous magnetic field. The circular polarization was obtained by a $\lambda/4$ plate. The laser power was approximately 2.3 W at the exit of the $\lambda/4$ plate. The laser beam was manipulated by a beam steerer so as to let the beam through the aperture of the Rb cell located 2.5 m away from the laser. In order to monitor the Rb polarization, another laser beam is shot into the cell to take advantage of the Faraday rotation method: The polarization is measured through the rotation of the polarization axis of a linearly polarized laser beam (probe laser) which goes through the Rb cell. The rotation angle is expressed as

$$\theta = V_1(\lambda, B)\rho B + V_2(\lambda, B)\rho P,$$

where P, B and ρ denote the polarization of Rb, the magnetic field strength and the Rb density, respectively, and the coefficients V_1 and V_2 are the "Verdet constants" which depend on B and the wave length λ of the probe laser. A diode laser associated with an external cavity (manufactured by Environmental Optical Sensors Inc., wavelength 780 nm, line-width 4 MHz, maximum power 18 mW) is used for the Faraday rotation measurements. The rotation

angle is measured by monitoring the intensity of the probe laser after passing through the cell, with a linear polarizer in front of a photodiode (HAMAMATSU S2281) being rotated.

Figure 1 shows a typical example of the results of the Faraday rotation measurements. The probe laser intensity is plotted as a function of the angle of the linear polarizer. The phase difference between the curves corresponds to the Faraday rotation angle. From the measurement when the pumping laser is turned off ($P = 0$), the Rb density can be determined. Then the polarization P is measured when laser is turned on. It is to be noted that the experimental curves are very smooth and free from noise. This implies that the rotation angles have been accurately measured, and the Rb density and the Rb polarization therefore have been determined very precisely. Figure 2 shows the Rb polarization as a function of the Rb density. It is to be noted that very high polarization has been achieved at the density around 10^{14} atoms/cm^2. It is concluded that sufficiently high polarization has been achieved. We will soon be ready to produce the polarization of the heavy-ions.

References

[1] K. Yonehara *et al.*, RCNP Annual Report 1996, p.134.

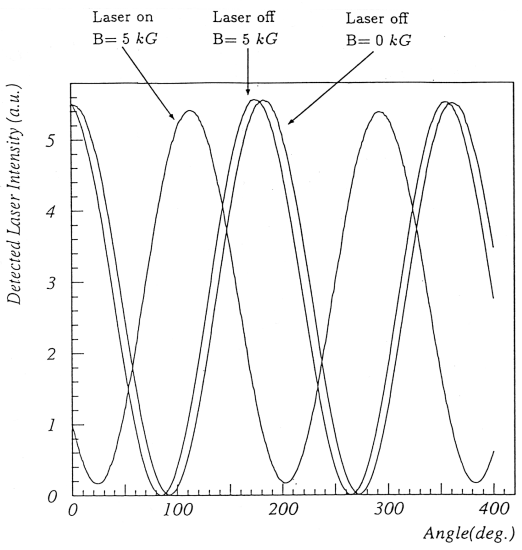

Figure 1: Results of Faraday rotation measurements.

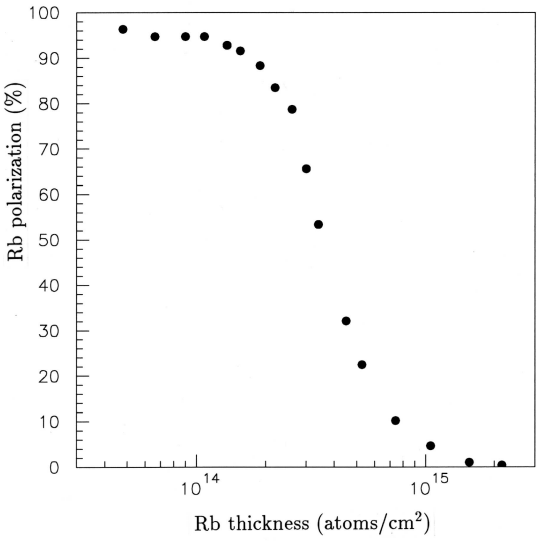

Figure 2: Rb polarization as a function of Rb thickness.