Development of Polarized ^{3}He Ion Source Based on Electron Pumping

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The polarized ^{3}He ion source based on electron pumping method is being developed at RCNP. Last year, we reported that evidence for electron pumping was observed in an indirect way [1]. After that, in August 1998, we directly observed the electron pumping from the measurement of the ^{3}He nuclear polarization by varying the thickness of polarized Rb vapor. We will show the experimental results, after summarizing a theoretical description of the electron pumping.

The rate equation for the electron pumping method is discribed by the following matrix form.

Rb polarization = +1 (Complete polarization)

$$\frac{d}{d\pi}\boldsymbol{H} = \boldsymbol{R_+}\boldsymbol{H}$$

$$\boldsymbol{H} = \begin{pmatrix} H^+_{1/2} \\ H^+_{-1/2} \\ H_{t1} \\ H_{t0} \\ H_{t-1} \\ H_{s0} \end{pmatrix}, \quad \boldsymbol{R_+} = \left(\begin{array}{cc|ccc|c} -\sigma_{10} & \sigma_{SEI} & \sigma_{t1} & \frac{\sigma_{t1}}{2} & 0 & \frac{\sigma_{s1}}{2} \\ 0 & -\sigma_{10}-\sigma_{SEI} & 0 & \frac{\sigma_{t1}}{2} & \sigma_{t1} & \frac{\sigma_{s1}}{2} \\ \hline \sigma_{10} & \frac{\sigma_{10}}{2} & -\sigma_{t1} & \sigma_{SEA} & 0 & 0 \\ \frac{\sigma_{10}}{2} & \frac{\sigma_{10}}{2} & 0 & -\sigma_{t1}-\sigma_{SEA} & \sigma_{SEA} & 0 \\ 0 & \frac{\sigma_{10}}{2} & 0 & 0 & -\sigma_{t1}-\sigma_{SEA} & 0 \\ \hline \frac{\sigma_{10}}{2} & \frac{\sigma_{10}}{2} & 0 & 0 & 0 & -\sigma_{s1} \end{array}\right)$$

Where $\boldsymbol{R_+}$ is a matrix for Rb vapor whose spin direction is +.

Rb polarization = P_{Rb} (Arbitrary polarization)

$$\frac{d}{d\pi}\boldsymbol{H} = (\epsilon_+\boldsymbol{R}_+ + \epsilon_-\boldsymbol{R}_-)\boldsymbol{H}$$

$$\boldsymbol{R}_- = \boldsymbol{T}\boldsymbol{R}_+\boldsymbol{T}^{\mathrm{T}}, \quad \boldsymbol{T} = \left(\begin{array}{cc|ccc|c} 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 & 1 \end{array}\right), \quad \begin{cases} \epsilon_+ = \dfrac{1+P_{\mathrm{Rb}}}{2} \\ \epsilon_- = \dfrac{1-P_{\mathrm{Rb}}}{2} \end{cases},$$

$$\sigma_{10} = \sigma_{1t} + \sigma_{1s}$$

where σ is a cross section either for charge transfers or for spin-exchange and each definition is referred to [2].

The experimental setup is shown in figure 1. $^3He^+$ extracted from the duo-plasmatron ion source is accelarated up to 19 keV and analyzed by the D1 magnet. Then $^3He^+$ is transported to the Rb cell where the electron pumping takes place [4]. The $^3He^+$ with the atomic polarization coming out of the region of the magnetic field is then nuclear polarized through the hyperfine interactions. After ^3He is separated by the electrostatic analyzer, the nuclear polarization of ^3He is measured by the beam-foil polarimeter [3].

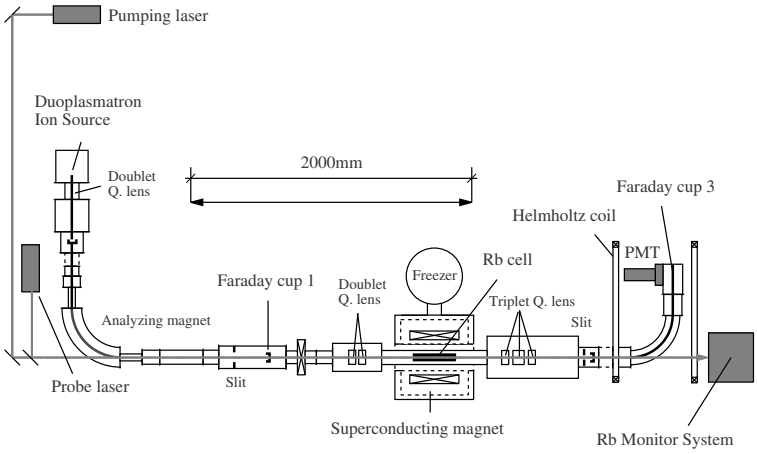

Figure 1: Whole layout of the experimental apparatus.

The observed polarization transfer coefficients, P_T defined by

$$P_T = \frac{2P_{He}}{P_{Rb}}, \qquad (1)$$

are plotted as a function of the Rb vapor thickness, where P_{He} is nuclear polarization of ^3He and P_{Rb} is Rb polarization.

The results of the theoretical calculations are also plotted; The solid curve is the full calculation, dash-dot curve is the calculation without spin-exchange and dashed curve is the result with stripping crossection reduced to half of the original one. It is concluded that the experimental results are qualitatively reproduced by the theory. This result clearly demonstrates the evidence for the electron pumpin.

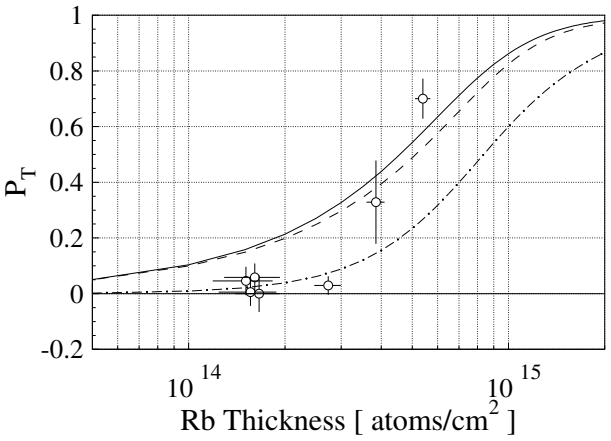

Figure 2: Measured P_T as a function of Rb thickness.

However, further investigation should be needed for firm establishment of the principle of electron pumping.

References

[1] M. Tanaka *et al.*, RCNP Annual Report (1997).

[2] M. Tanaka *et al.*, Phys. Rev. **A52** (1995) 392.

[3] Y. Arimoto *et al.*, RCNP Annual Report (1998).

[4] K. Yonehara *et al.*, RCNP Annual Report (1998).