Complete Determination of Spin Exchange Process for Improved ^{129}Xe image

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Introduction

The first MRI images of gas in lungs were acquired using laser polarized xenon[1]. However, ^{3}He became the choice of hyperpolarized gas imaging for the last decade because scientific community could not obtain highly polarized ^{129}Xe gas until recently. The University of New Hampshire group can now obtain over 45% polarization at a rate of 1.2 liters per hour which is comparable to the polarization of ^{3}He. The success of the University of New Hampshire polarizer came from operating the polarizer in low pressure regime, where the Rb-Xe spin exchange rate is an order of magnitude higher than high pressure regime[2]. Further improvement in our world leading polarizer will require precision methods of characterizing and understanding spatial and temporal properties of the spin exchange. With compact diagnostic tools, such as Faraday rotation, EPR and alkali absorption lasers, one can characterize the optical pumping process and improve the polarization of ^{129}Xe to even higher level.

Material and Method

The Figure 1 shows the schematic of the diagnostic devices. A 100 mW diode laser with a beam collimator is powered by a current laser driver. The temperature of the laser is regulated by a temperature controller. In Littrow configuration, the laser is mated with a holographic diffraction grating. The grating with 1800 lines/mm is then adjusted so that the first order diffraction is reflected back into the laser. The lasing wavelength is determined by the angle of the grating. The power is coupled out along the zeroth order diffraction (normal to the grating). A constant magnetic field, B between 0 to 60 gauss is applied over the cell parallel to the probe beam, using a pair of Helmholtz coils. The cylindrical cell is placed in a hot air oven and is heated between 67C and 157C in order to obtain various rubidium number densities. First level suppression of fluorescent and stray background lights due to pump beam is achieved by using a small black iris of 3mm diameter. A Glan-Thompson prism is used to split the laser into parallel and perpendicular polarization beams with respect to the main cut of the prism. The two beams come out with approximately 45 degree opening angle and the intensity of each beam is measured on photodiodes separately. Second level suppression of background light is achieved by using Labview software Lock-In amplifier. The photodiodes signals are fed into a PC, using a data acquisition card when the two diode signals are correlated with the reference from the chopper. The angle of polarization with respect to the prism cut is calculated from the intensity measurements of two diodes. This calculation of the angle is done on the fly and is recorded in the data stream to reduce the systematic fluctuations.

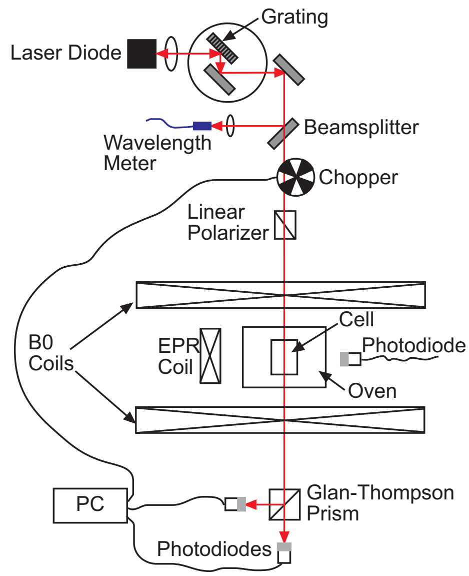

Fig.1: Schematic of polarizer and diagnostic tools.

Results

The Faraday rotation angle is measured as a function of wavelength and fitted to the theoretical curve as shown in Figure 2. The fit produces the best result when the product is 7.96E12cm^{-3}. In order to further verify our technique, we have compared our result with well known density, measurements done by Killian[4]. In 1926, Killian demonstrated that for a rubidium in a close system, the number density only depends on its temperature. Therefore, the Faraday rotation data in a 10cm long cylindrical cell are taken at various temperatures, 85C, 100C, 110C and 120C and fitted to the theoretical curve to obtain the product. The density characteristic to each of the temperatures was obtained assuming Rb polarization equal to 100%. Figure 3 shows the density measurement from our compact Faraday rotation device. This demonstrates that the Faraday rotation device is very sensitive for measuring the rubidium density and polarization.

Outlook

The implementation the Faraday rotation device will be used for the pump laser alignment, and as well as for monitoring the density and polarization of Rb. The EPR device has been constructed and undergoes testing. We plan to measure ^{129}Xe and Rb polarization. Absorption technique at 780nm revealed that the absorption was too strong to measure the density of Rb. We have redesigned our experiment with 420nm violet laser and more accurately recalculated the theoretic prediction. Using the diagnostic tools, we will refine our theory and improve the polarization of ^{129}Xe.

Acknowledgement

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References

1. M.S. Albert et al., *Nature* **370** 199-201 (1994)
2. B. Chann et al., *Phys Rev Lett* **88** (11) 2002
3. I.C. Ruset, *et. al.*, *Large Production of Highly Polarized* ^{129}*Xe and Delivery*, the 2004 International Workshop on Pulmonary Function Imaging at Penn, Philadelphia, PA, Nov. 12-14, 2004
4. T. Killian, *Phys Rev* **27**, 57 (1926)
5. I. Nelson, *Physics of optical spin-exchange optical pumping*, PhD Thesis, University of Wisconsin, 22 (2001)

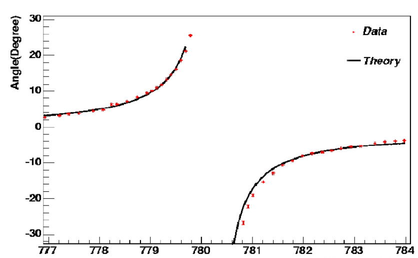

Fig.2: At B=40 gauss the product P*N=7.96e12cm^{-3} of Rb number density, N, and its polarization, P, is used to fit the data. Small statistical error indicates that the measurement is stable. Data on the right side were taken before the pump laser became stable to check the sensitivity due to the polarization effect.

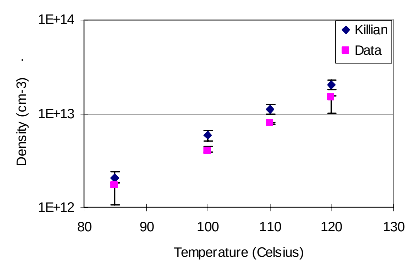

Fig.3: The y-axis is in log-scale. Error bars on Killian's points are from the uncertainty in temperature. There is 25% discrepancy between the two measurements due to wall relaxation and other effects. This was also observed in Wisconsin group[5].