Scaling Up 129Xe Hyperpolarization - A Diagnostic Tools System

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Introduction:

Hyperpolarized xenon enhances the sensitivity of Magnetic Resonance Imaging (MRI) by at least five orders of magnitude, which opens new possibilities in the field of lung imaging previously limited by signal-to-noise-ratio [1]. Also, due to its solubility in blood and high sensitivity to chemical environment ^{129}Xe has great capability in functional investigations of organs beyond the lungs. A higher quantity of hyperpolarized gas with high polarization is a continuous demand in the research community.

A new approach to xenon polarization in which the gas is flowed in a long cell at low pressure opposite to the direction of the laser beam has been demonstrated to achieve a magnetization of xenon one order of magnitude higher than previously reported polarizing systems [2]. The diagnostic tools presented here provide a fundamental approach to understand the spin-exchange process between optically pumped Rb and ^{129}Xe in a regime of pressure, temperature, gas mixture and laser power that has never been studied before. The results are important parameters for theoretical simulation codes and of general interest for designing future generation polarizers.

Methods:

Our test cell contains Rb and can be filled by our gas flow panel with varying gas mixtures of nitrogen, helium and xenon. The cell is placed in a double-shell oven made of Teflon which ensures a uniform temperature distribution and can be heated up to 200C by hot air flow. Two large Helmholtz coils provide the longitudinal B_0 field. For effectively pumping of Rb, a single-bar high power diode laser is narrowed in an external cavity and tuned into resonance with the D_1 absorption line [3]. The two probe lasers are low power diode lasers which can be scanned in an external Littrow cavity configuration over a wavelength range of 7-10 nm. The experiments are controlled by programs written in Labview software which also allow data evaluation on the fly.

The two diagnostic methods presented here are based on the interaction of the Rb vapor and resonant light. The Faraday rotation experiment makes use of the optical birefringent property of the Rb vapor, when placed in an external magnetic field. The plane of polarization of a linearly polarized probe beam is rotated after traveling through the cell. Since the Faraday rotation angle can be very small, we use a photoelastic modulator to detect the signal. Data are taken by measuring the Faraday rotation angle as the probe beam is scanned over the D_2 resonance line of the Rb vapor. From a fit to the theoretical formula Rb density and polarization can be extracted, if treated as free parameters.

A few additional components allow us to measure Rb spin-destruction with a method known as “relaxation in the dark”. The high power D_1 pump laser is chopped at a frequency low enough to ensure complete re-polarization of Rb in the cell between measurements. When the pump beam is blocked, the exponential decay of Rb polarization is monitored by measuring the Faraday rotation angle. From the polarization decay curve one can extract the Rb spin-destruction rate.

A second and unique diagnostic tool is absorption spectroscopy on the $5S_{1/2} – 6P_{1/2}$ (421.5 nm) and $5S_{1/2}–6P_{3/2}$ (420.2 nm) Rb energy level transitions. The probe laser is a violet diode laser (Nichia Corp.) which is frequency-locked and scanned over the two resonances. The monitored transitions have much lower oscillator strengths than the Rb D_1 and D_2 lines and therefore allow absorption spectroscopy in optically thick Rb vapor without being completely absorbed at resonance. By measuring the depth and width of the absorption lines we obtain the Rb density. As it was never studied or used before at this level of accuracy, this method is presently under precise calibration against the Faraday rotation. We will study pressure broadening effects on these energy levels. The advantage of measuring Rb density through this method is that it can be done precisely even when Rb is optically pumped and polarized.

Results:

The Faraday rotation angle as a function of wavelength is shown in Fig.1. The fit to the theoretical formula gives a Rb density of 5.31 x 10^{13} cm^{-3}. This is about 30% lower than the value extracted from reported vapor pressure curves at this temperature [6]. Measuring Rb density instead of extracting it from literature empirical curves greatly reduces errors. Rb spin destruction measured with “relaxation in the dark” is shown in Fig.2. The total Rb spin destruction constant is obtained from a fit to the exponential decay of Rb polarization at late times. The contributions from Rb wall relaxation, Rb-Xe binary collisions and Rb-Xe van der Waals molecule formation can be singled out by testing different gas compositions at varying total density. High laser power can result in large temperature elevation inside the gas mixture [4] leading to Rb density runaways [5] for closed cells and polarizers where the Rb metal reservoir is placed inside the optical pumping region. This effect is demonstrated by the violet laser data shown in Fig.3.

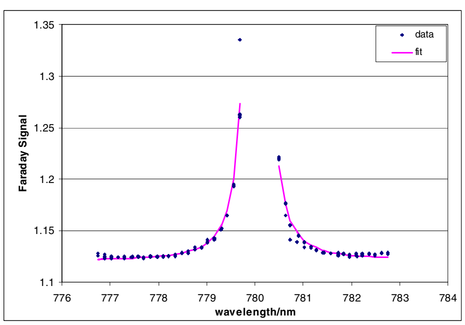

Fig.1: Faraday rotation angle as a function of wavelength at a temperature of 144C. The fit gives a Rb density of 5.31 x 10^{13} cm^{-3}.

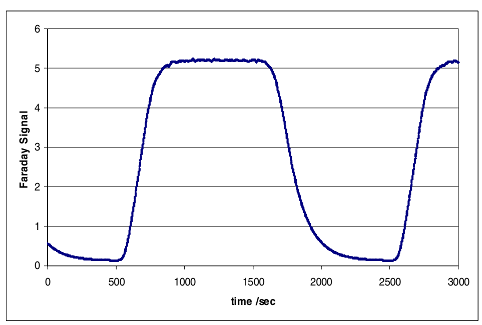

Fig.2: Rb polarization relaxation measured with “relaxation in the dark”. The fit to a single exponential in the region of decay gives the total Rb loss rate.

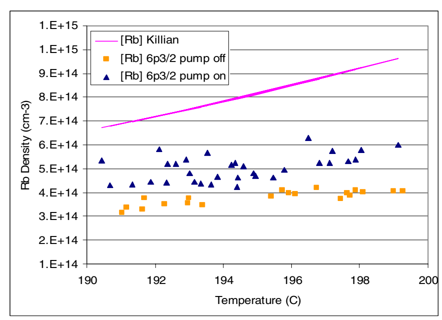

Fig.3: Rb density runaways. Rb density measured with absorption spectroscopy shows higher values as the pump beam is turned on.

Conclusion:

Faraday rotation and absorption spectroscopy allow precise measurements of spin-exchange constants and their dependence on various parameters. An unexpected saturation of polarization with increasing pump laser power was reported previously [2]. We believe this to be caused by local heating of the gas mixture due to absorption of the pumping light and a resulting decrease of efficiency in the spin exchange process. It is thus of particular interest for us to study the temperature dependence of spin-exchange and spin-destruction constants with the here presented diagnostic tools.

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