Transverse Measurements of Polarization in Optically-Pumped Rb Vapor Cells

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In optical-pumping of alkali-metal vapors, polarization of atoms is typically determined by probing along the entire length of the pump beam, resulting in an averaged value of longitudinal polarization. Unfortunately, these measurements do not give information about spatial variations of polarization along the pump beam's propagation distance. Using a D1 probe beam oriented perpendicular to the pump beam, we have demonstrated a heuristic method for measuring polarization. This method has possible applications in mapping atomic polarization in alkali-metal vapor cells.

Transverse Probe Beam:

We consider an optically-pumped alkali-metal vapor where a pump beam is parallel to an imposed magnetic field along the z quantization axis. Linearly-polarized light oriented transverse to the pump beam can have two different polarizations: π (polarization axis parallel to the z-axis), and π_y (polarization axis perpendicular to the pump beam). Fig. 1 shows the allowed transitions for such beams.

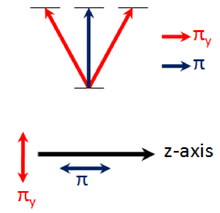

Fig. 1: Allowed transitions for transverse polarized light. π light drives $\Delta m_f = 0$ transitions, and π_y light has an equal chance to drive $\Delta m_f = +1$ and $\Delta m_f = -1$ transitions.

A maximally-polarized vapor with all atoms having $m_f = +F$ in the ground state will be transparent to a π probe beam tuned to a transition with $F_g > F_e$, where F_g and F_e are the degeneracy of the ground and excited states respectively (see Fig. 2). If the probe is π_y, the atoms may be excited. Thus, π_y light is more strongly absorbed than π light.

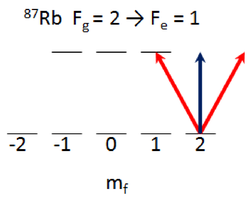

Fig. 2: Possible transitions from the F = 2, m_f = 2 ground state to the F = 1 excited state driven by transverse linearly polarized light.

Conversely, if a transverse probe beam is tuned to a transition for which $F_g = F_e$, there is always the opportunity for π light to be absorbed regardless of m_f (see Fig. 3). However, for a completely spin-polarized vapor, half the absorption of π_y light is suppressed. Therefore, π light will be preferentially absorbed compared to π_y light.

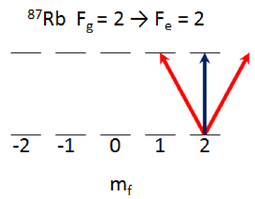

Fig. 3: Possible transitions from the F = 2, m_f = 2 ground state to the F = 2 excited state driven by transverse linearly polarized light.

Finally, if a transverse probe beam is tuned to a transition with $F_g < F_e$, the absorption probability is determined by relevant Clebsch- Gordan coefficients.

Experimental Results:

An absorption profile was obtained for both a π and π_y probe beam passed transversely through a cylindrical cell of optically-pumped Rb vapor. The cells were 4.3 cm long and 2.5 cm in diameter and contained 10 torr of N_2 buffer gas. The profile of the π probe was subtracted from that of the π_y probe to give a difference signal. As can be seen in the data in Fig. 4, the most prominent feature in the difference signal corresponds to π_y light being more strongly absorbed than π light near the ^{87}Rb $F_g = 2 \rightarrow F_e = 1$ transition. Other features predicted in the previous discussion are visible to some extent. The exception to this is near the ^{85}Rb $F_g = 3 \rightarrow F_e = 2$ transition, which preferentially absorbs π_y light, and the ^{87}Rb $F_g = 2 \rightarrow F_e = 2$ transition, which preferentially absorbs π light. Because these two transitions are separated by less than 1 GHz, the effects cancel.

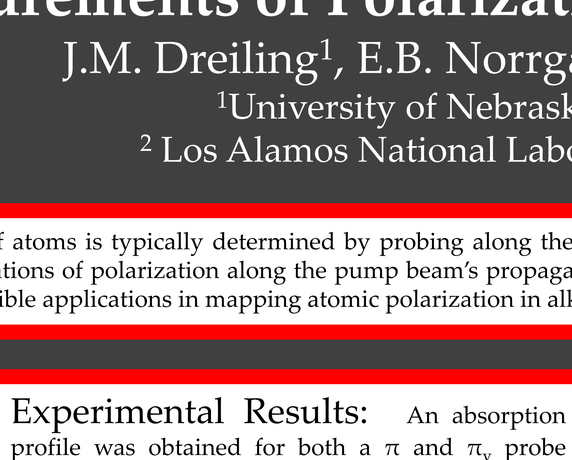

Fig 4: Absorption profiles for transverse π_y and π light and the difference between those two signals (π_y - π)for Rb densities of $2.4{\cdot}10^{12}$ cm^{-3} and 10 torr N_2 buffer gas. The positions of hyperfine transitions are given at the bottom of the graph. From left to right: ^{87}Rb $F_g = 2 \rightarrow F_e = 1$, ^{87}Rb 2 → 2, ^{85}Rb 3 → 2, ^{85}Rb 3 → 3, ^{85}Rb 2 → 2, ^{85}Rb 2 → 3, ^{87}Rb 1 → 1, ^{87}Rb 1 → 2.

Analysis:

The minimum value of the normalized difference signal corresponding to the ^{87}Rb $F_g = 2 \rightarrow F_e = 1$ transition , D, was plotted versus P_{Rb}, the polarization measured using longitudinal Faraday rotation [1]. This was done for five Rb densities, N, each with 10 torr of N_2 buffer gas (Fig. 5).

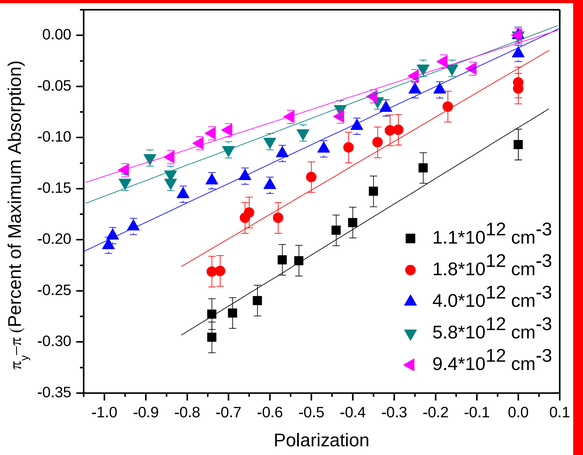

Fig. 5: Difference signal plotted versus measured longitudinal polarization. Data was taken for five different Rb densities.

The data was fit to a line of the form

$$D = A + B{*}P_{Rb}. \quad (1)$$

Fig. 6 shows A and B are dependent on Rb number density (measured in 10^{12} cm^{-3}). One can obtain A and B from the empirical equations

$$A = [22(11) - 30(10){*}N]^{-1} \quad (2)$$

and

$$B = [3.36(0.10) + 0.52(0.04){*}N]^{-1}. \quad (3)$$

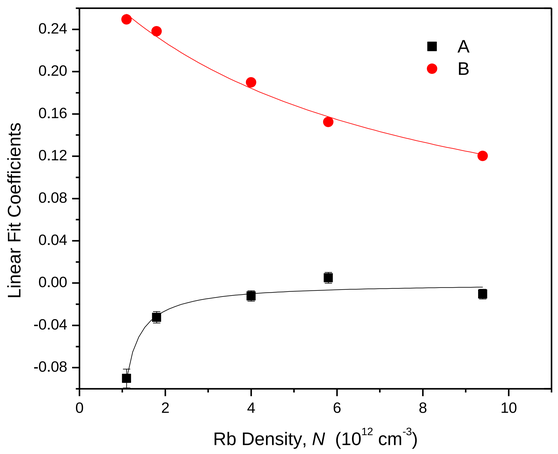

Fig. 6: Dependence of linear fit coefficients in Eq. 1 versus Rb density. The fits correspond to Eqs. 2 and 3.

Validation:

Two more measurements of D versus P_{Rb} were performed at Rb densities of $1.3{\cdot}10^{12}$ cm^{-3} and $9.6{\cdot}10^{12}$ cm^{-3}. Based on the measured value of N, the coefficients A and B were calculated. The predicted value of P_{Rb} was compared to the value measured using the standard longitudinal Faraday rotation technique. The polarization predicted by transverse absorption is plotted in Fig. 7 versus polarization measured by the longitudinal Faraday method. As a guide for the eye, the line $P_{absorb} = P_{Faraday}$ (i.e. when both methods are in perfect agreement) is shown in green.

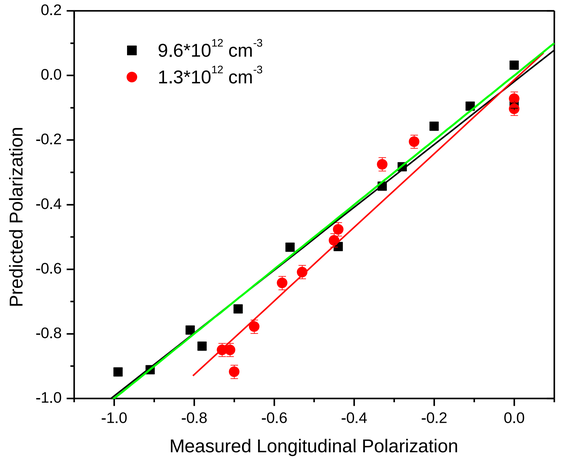

Fig. 7: Comparison of measurements performed using the longitudinal Faraday rotation method and the transverse absorption method.

Potential Application:

The transverse probe beam method for determining polarization has potential applications in mapping the spatial variation of the polarization in a cell of optically pumped Rb vapor. This has an advantage over traditional Faraday rotation in that it is relatively simple to set up.

References:

[1] H. Batelaan, A.S. Green, B.A. Hitt, and T.J. Gay, Phys. Rev. Lett. **82**, 4216 (1999).

This work was supported by NSF Grant PHY-0855629 and PHY-0821385 (MRI) and is unclassified: Los Alamos Unlimited Release LA-UR 10-02789.

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