Nonlinear precession of the polarization ellipse in resonant atomic media: two-level systems and Rb

D. Budker[a,b], **R. Y. Chiao**[a], **D. S. Hsiung**[c], **S. M. Rochester**[a], **and V. V. Yashchuk**[a,d]

[a] *Department of Physics, University of California, Berkeley, CA 94720-7300*
[b] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley CA 94720*
[c] *Department of Electrical Engineering and Computer Science, University of California, Berkeley, CA 94720*
[d] *B.P.Konstantinov Petersburg Nuclear Physics Institute, Gatchina, Russia 188350*
(510)643-1829, (510)643-8497, budker@socrates.berkeley.edu

Abstract: Experimental and theoretical results are presented for resonant self-rotation for Rb atoms in buffer-gas-free uncoated cell and paraffin-coated cell. The effect is drastically different in the two cases.

OCIS codes: 190.5940 Self-action effects; (270.1670) Coherent optical effects

Self-rotation (SR) of the polarization ellipse upon propagation through a nonlinear medium was among the first nonlinear optics phenomena observed [1]. SR in resonant atomic vapors has been the subject of several theoretical and experimental studies (see e.g. [2, 3] and references therein). Here we describe SR in two-level $F \to F'$ systems (F, F' are the total angular momenta of the lower and the upper state) and present experiments and theoretical interpretation (based on density matrix calculations) of SR on the Rb $D_{1,2}$ lines.

The important properties of SR for the two-level systems can be summarized as follows:

- In the absence of Doppler broadening and collisions, all $F \to F'$ transitions display SR, except for $0 \to 1$, $1 \to 0$, $1 \to 1$. An explanation of this result from consideration of "dark" and "bright" Zeeman sublevel systems will be presented.

- Repopulation of the lower state by spontaneous decay of the upper state significantly affects the magnitude (and in the case of $F \to F + 1$ transitions, also the sign) of SR.

- In the presence of Doppler broadening, the magnitude of SR (per absorption length) is reduced by γ/Γ_D, where γ is the natural width of the transition and Γ_D is the Doppler width.

In the Rb system with multiple hyperfine levels, it is important to take into account effects beyond the two-level approximation such as multi-level repopulation pumping and AC Stark shifts in order to adequately reproduce experimental observations.

We have carried out measurements of SR in two Rb vapor cells without buffer gas. One of the cells had an anti-relaxation coating. Details of the experimental apparatuses can be found in [4]. A comparison of the experimental and theoretical results for the uncoated cell is given in Fig. 1. The theoretical curves were obtained from a density matrix calculation incorporating the multi-level effects. For comparison, the results of measurements and calculations for the transmission and nonlinear Faraday rotation spectra [4] are also shown in Fig. 1. For the coated cell, we find that both the magnitude and the spectral dependence of SR are markedly different from the case of the uncoated cell. For example, there is no γ/Γ_D suppression for the coated cell, so the magnitude of the effect is generally larger. We have investigated the dependence of SR on the magnitude and the direction of the applied magnetic fields (Fig. 2). This technique allows one to separate the effects of the light-induced orientation and alignment on the optical properties of the atoms.

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References

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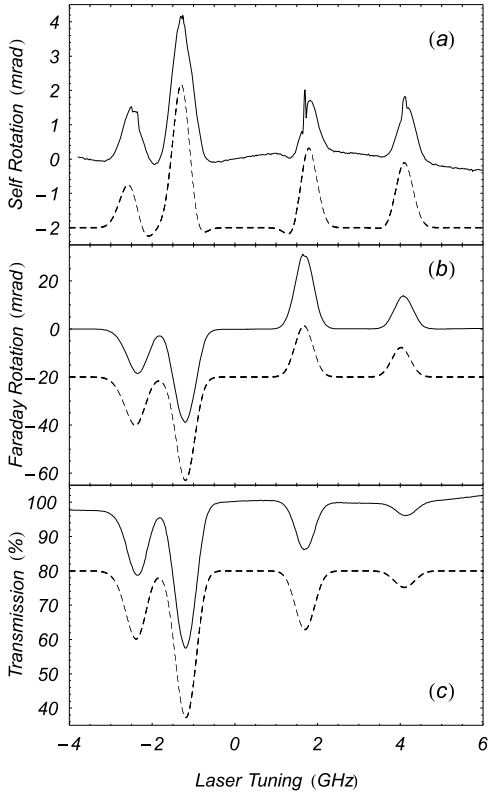

Fig. 1. Data (solid lines) and theory (dashed lines) for (a) self rotation, (b) Faraday rotation, and (c) transmission on the D_2 line of Rb. Theoretical curves are vertically displaced for comparison. Laser power is approximately 0.12 mW, laser beam dimensions are $\sim$ 1 mm. Rb density is $\sim 10^{10}$ atoms/cm^3. Cell length is 5 cm; it contains natural mixture of ^{85}Rb and ^{87}Rb. For the SR data, the ellipticity of the input laser light is approximately 0.1 rad. For the Faraday rotation data, a magnetic field of about 125 mG is applied along the direction of light propagation. Parameters of the theory were chosen within experimental uncertainties to best fit the data. The sharp Doppler-free features seen most clearly in SR near the center of the resonances are believed to be due to the light reflected from the output window of the cell.

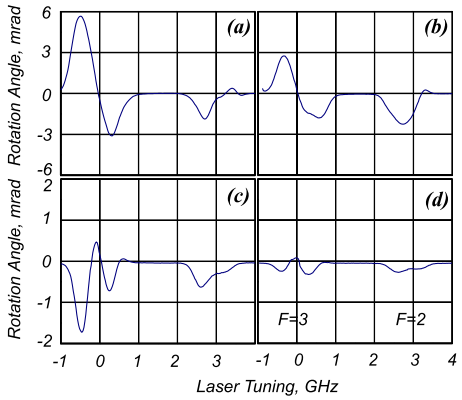

Fig. 2. Self rotation data on the D_1 line for the coated vapor cell (10 cm diam) containing isotopically pure ^{85}Rb. SR is shown in the absence of magnetic fields (**a**), and with magnetic fields applied along $\hat{z}$ (**b**), $\hat{y}$ (**c**) and $\hat{z}$ (**d**). The magnitude of the fields, $B = 100$ μG, is chosen to be much larger than the range where magneto-optical rotation due to the wall-induced Ramsey effect is significant, and much smaller than the range where the transit effects are significant [4]. Light propagates along $\hat{z}$ and the initial major axis of the polarization ellipse is along $\hat{y}$. Initial ellipticity is approximately 35 mrad. Laser power is approximately 1 mW, laser beam dimensions are $\sim$ 3.5 mm. Rb density is approximately $4 \cdot 10^9$ atoms/cm^3.

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