New developments in nonlinear optical rotation

D. Budker [1], D. F. Kimball, S. M. Rochester, and V. V. Yashchuk

Physics Department, University of California
Berkeley, CA 94720-7300
Tel (510)643-1829, Fax (510)643-8497
E-mail: budker@socrates.berkeley.edu, Website: http://phylabs.berkeley.edu/budker/
[1] *Also with Nuclear Science Division*
Lawrence Berkeley National Laboratory, Berkeley, CA 94720

Recent investigations have shown that measurements of nonlinear optical rotation related to the evolution of light-induced atomic polarization may be among the most sensitive techniques for detecting shifts of Zeeman sublevels (sensitivity $\sim 10^{-6}$ Hz/$\sqrt{\text{Hz}}$) [1]. Nonlinear optical rotation can therefore be applied to precise electric and magnetic field measurements [1, 2], as well as sensitive tests of fundamental symmetries [3, 4, 1]. Nonlinear optical rotation is also closely related to phenomena such as electromagnetically induced transparency and dark resonances [5, 6], as demonstrated in the study of light propagation dynamics [7]. Here we present recent advances in the understanding and applications of nonlinear optical rotation.

1. **Sensitive Magnetometry using Nonlinear Magneto-Optical Rotation (NMOR).**

We have performed a systematic study of the shot-noise-limited sensitivity of an NMOR-based magnetometer as a function of light intensity, light frequency, atomic density, and laser beam diameter. The magnetometer consists of a modulation polarimeter which measures rotation of the polarization plane of a laser beam resonant with transitions in Rb. Rb vapor is contained in an evacuated cell with antirelaxation coating [8] which enables atomic ground state alignment to survive many thousand wall collisions. This leads to ultranarrow ($\sim 10^{-6}$ G) dispersion-like features in the magnetic field dependence of optical rotation [1]. It is shown that through an appropriate choice of parameters the shot-noise-limited sensitivity to small magnetic fields can surpass 3×10^{-12} G/$\sqrt{\text{Hz}}$ [1], about an order of magnitude improvement over conventional optical pumping magnetometers.

2. **NMOR via Alignment-to-Orientation Conversion.**

At high light intensities a previously unrecognized mechanism, alignment-to-orientation conversion [10] due to the combined action of the magnetic field and light electric field, has been found to play an important role in NMOR [9]. It is found to be the primary mechanism responsible for NMOR at the light frequencies and intensities where the highest sensitivity to magnetic fields is achieved [1]. This effect leads to a change of the overall sign of rotation for closed $F \to F+1$ transitions as light power is increased. The effect is demonstrated by measurements in Rb and density matrix calculations.

3. **NMOR in separated light fields.**

NMOR in rubidium vapor contained in a paraffin-coated cell has also been investigated using the method of separated pump and probe laser fields [11]. With appropriate choice of laser frequencies, strong rotation signals can be obtained when pump laser light is resonant with a transition from one hyperfine level of the ground state and optical rotation is measured in another. This technique may be applied to magnetometry.

4. **Nonlinear Self-rotation.**

Self-rotation (SR) of the light polarization ellipse was among the first nonlinear optics processes studied at the dawn of the laser era [12]. In collaboration with R. Y. Chiao and D. S. Hsiung, we have recently investigated SR in near-resonant atomic media [13]. SR can lead to systematic effects in optical rotation measurements, and is thus important in work employing optical rotation for precision measurements.

5. **Nonlinear Electro-Optic Effects (NEOE).**

We are also investigating nonlinear optical effects which arise when near-resonant light propagates in an atomic medium in the presence of an electric field. NEOE can be applied to sensitive measurements of permanent electric dipole moments [3, 4, 1], as well as for non-intrusive, spatially and temporally resolved electromagnetic field measurements.

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