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Weak Optical Measurements and Control of Atomic Spin Ensembles

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Optical polarization spectroscopy is uniquely suited as a continuous, non-destructive probe of the quantum state of an atomic spin ensemble, and provides an attractive starting point for studies of quantum measurement and control. I will broadly consider what information about the spins can be accessed, and also what kinds of spin dynamics can be driven by the atom-probe interaction. I will then discuss our recent work on optical measurement/control of the spin degrees of freedom of laser cooled Cs atoms. One experiment studies the use of Faraday rotation to probe the spin-angular momentum, and in particular the significance of tensor terms in the probe light shift Hamiltonian. The tensor terms are non-linear in the spin variables, and lead to easily observable collapse and revivals of a Larmor precessing spin-coherent state. We are now exploring the use of this non-linear term in the spin Hamiltonian to drive a more complex evolution that continually maps new information about the initial state onto the measured observable. In principle the measurement record can then be used to perform quantum state tomography non-destructively and in real time. In a second experiment we use a variation of the basic polarization spectroscopy setup to implement a continuous weak measurement of the pseudospin associated with the atomic clock transition in Cs. The measurement performance is comparable to Faraday rotation measurements of spin angular momenta, and the technique can therefore in principle be used to achieve measurement-induced squeezing of the collective pseudospin along the limes explored in [J. Geremia et al., Science 304, 270 (2004)]. Squeezing of the clock pseudospin is particularly interesting because it can be applied directly to the improvement of atom interferometers and atomic clocks.