Conditions for spin squeezing in a cold ^{87}Rb ensemble

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There has recently been much interest in coupling light with atomic ensembles to develop a quantum interface. Several proposals have been published to utilise this kind of interface for spin squeezing, quantum memories, quantum teleportation, and entanglement [1]. Many of these proposals have been realised experimentally. Spin squeezing is the simplest of these applications, and has been demonstrated several times. However, all of these realisations have been performed using squeezed states of light or samples in vapour cells with relatively low signal to noise ratio.

We propose a scheme to generate spin squeezing via a quantum non-demolition (QND) measurement [2] in a cold sample of ^{87}Rb atoms using the $5S_{1/2}(F=1)$ hyperfine ground state. In this system we expect to have a much higher signal to noise ratio than in previous work. Suitable Zeeman substates and operators to perform the QND interaction in this scheme are identified, together with the possible sources of error and noise arising from these choices.

Spin squeezing is created by sending an off-resonant pulse of light in a coherent polarisation state through an atomic sample prepared in a coherent spin state. The light and atoms exchange quantum fluctuations due to the dipole interaction; squeezing is then achieved by a QND measurement of one component of the atomic spin. The coupling between light and atoms in this kind of schemes is described by the fluctuation relations [2]

$$\delta\hat{J}_y^{out} = \delta\hat{J}_y^{in} + \kappa\delta\hat{S}_z^{in}, \qquad \delta\hat{J}_z^{out} = \delta\hat{J}_z^{in}, \tag{1a}$$

$$\delta\hat{S}_y^{out} = \delta\hat{S}_y^{in} + \kappa'\delta\hat{J}_z^{in}, \qquad \delta\hat{S}_z^{out} = \delta\hat{S}_z^{in}, \tag{1b}$$

where κ and κ' are coupling constants, $\hat{S}_y$ and $\hat{S}_z$ are components of the Stokes vector $\hat{\mathbf{S}}$ of light, and $\hat{J}_y$ and $\hat{J}_z$ are components of an atomic pseudo-spin vector $\hat{\mathbf{J}}$.

The ideal case of a spin-1/2 system is simple to consider [2], as $\hat{\mathbf{J}}$ corresponds to the real spin $\hat{\mathbf{F}}$, but is not easy to realise. For example, in a real ^{87}Rb system the lowest spin number is 1, and many states have to be considered (see Fig. 1). We show that in this situation a quasi-ideal system can be implemented using a coherent superposition of the $|5S_{1/2},\ F=1,\ m=\pm1\rangle$

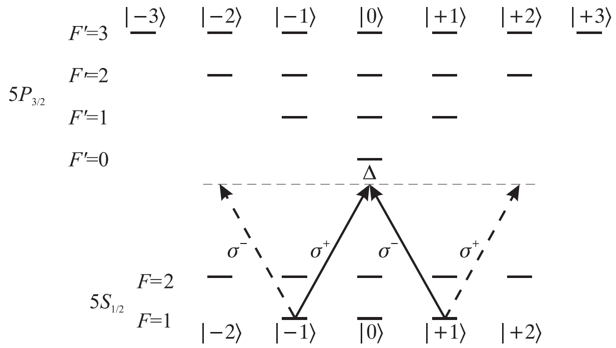

Figure 1: Levels and transitions relevant for spin squeezing on the D_2 line in ^{87}Rb.

states, and defining a pseudo-spin $\hat{\mathbf{J}}$

$$\hat{J}_x = \frac{1}{2}\left(\hat{F}_x^2 - \hat{F}_y^2\right),$$
$$\hat{J}_y = \frac{1}{2}\left(\hat{F}_x\hat{F}_y + \hat{F}_y\hat{F}_x\right),$$
$$\hat{J}_z = \frac{1}{2}\hat{F}_z.$$

One finds that the interaction of $\hat{\mathbf{J}}$ with $\hat{\mathbf{S}}$ is still of the QND form (1). When all states are considered, contributions from the $|5P_{3/2};\ F'=0,1,2;\ m=0\rangle$ states are at most partially cancelled by those from the $|5P_{3/2},\ F'=2,\ m=\pm2\rangle$ states, and the real system still behaves as the ideal one.

Major sources of noise arise in the preparation process if the coherent superposition is not done properly, or if there is population in any of the Zeeman ground states other than $|5S_{1/2},\ F=1,\ m=\pm1\rangle$.

References

[1] B. Julsgaard, *et al.*, "Experimental long-lived entanglement of two macroscopic objects," Nature **413**, 400-403 (2001).

[2] A. Kuzmich, *et al.*, "Atomic quantum non-demolition measurements and squeezing," Europhys. Lett. **42**, 481-486 (1998).