

Spontaneous Polarization in Cesium Vapor

R. B. Warrington, A. Andalkar, B. R. Heckel and E. N. Fortson

University of Washington, Physics Department, Box 351560, Seattle WA 98195

Spontaneous polarization is a novel mechanism for establishing a spin orientation by optical pumping in an alkali vapor. Unlike conventional optical pumping with circularly polarized light, spontaneous polarization occurs even with *linearly* polarized light—that is, when the pump light carries no angular momentum. Under appropriate conditions, the state of zero polarization becomes unstable, and the atomic spins will spontaneously align either parallel or antiparallel to an applied magnetic field [1, 2]. The spins can be induced to switch from one state to the other by applying a degree of circular polarization in the pump light; the new state will be maintained even if the pump polarization is returned to linear, giving rise to a striking hysteresis (Figure 1) analogous to ferromagnetism. Spontaneous polarization may have important applications in the search for a permanent electric dipole moment (EDM) and in spin-exchange pumping of noble gases.

To illustrate the important features of the spontaneous polarization mechanism, consider the D1 ($s_{1/2} \rightarrow p_{1/2}$) resonance transition of a heavy alkali, with excitation on only the $F \rightarrow F+1$ hyperfine component ($F = I - 1/2$). The angular momentum coupling coefficients for this component are such that $|m|$ is more likely to increase than decrease, so that any slight bias in polarization $\langle m \rangle$ will be amplified after excitation; this provides the gain for the pumping cycle. The gain in polarization can be preserved by using a nitrogen buffer gas to provide collisional quenching from the excited state, avoiding light emitted during radiative decay which can otherwise act to depolarize other atoms in the vapor. Finally, quenching repopulates both ground state hyperfine levels but only one is addressed by the pump light, so alkali-alkali spin exchange collisions are necessary to transfer

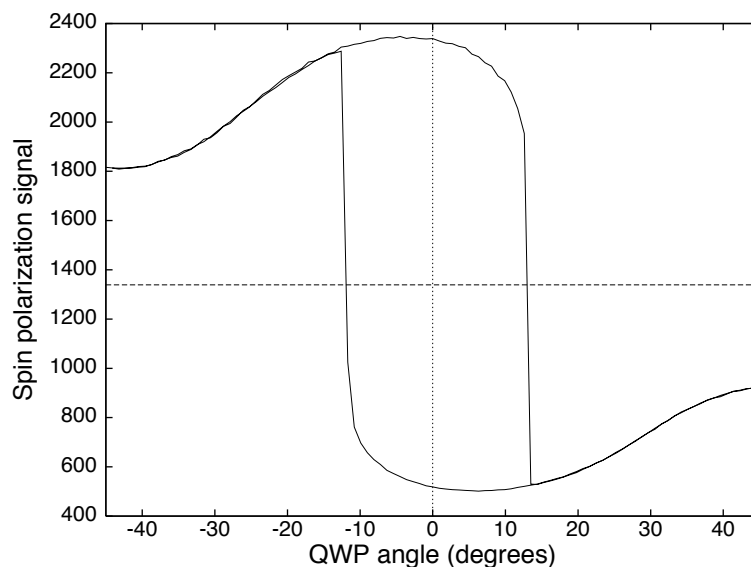


Figure 1: Experimental hysteresis curve for spontaneous polarization in cesium vapor, showing atomic spin polarization versus the degree of circular polarization of the pump light (given by the orientation of a $\lambda/4$ plate in the pump beam). There are two stable states of nonzero spin polarization for linearly polarized light (vertical line), and the spin polarization can be induced to switched between these as the pump light polarization is varied. The horizontal line gives the spin polarization in the absence of the pump.

population back to the optically pumped level and complete the cycle. These collisions change F but preserve m .

In the absence of spin relaxation there are thus only two stable states, with all the spins aligned either parallel or antiparallel to the applied field, where the excitation and spin exchange rates vanish. Any tiny bias in polarization towards either state will be amplified by the cycle described above until the stable state is reached. In practice, an equilibrium polarization $\langle m \rangle$ will evolve spontaneously whenever the rates of spin exchange and optical excitation are greater than the spin relaxation rate. The initial bias in polarization may be imposed by experimental conditions, or it can even arise from statistical fluctuations in the state populations alone. When the pump light is elliptically polarized, spontaneous polarization and conventional optical pumping compete, so that applying a sufficient degree of circularity will switch the polarization from one stable state to the other. This gives rise to the striking hysteresis curve shown in Figure 1.

The mechanism for spontaneous polarization was first predicted over ten years ago [1], and was observed for the first time two years ago in this laboratory [2], for the $F = 3 \rightarrow F = 4$ component of the D1 transition in cesium at 894 nm. Since then we have been conducting a detailed study, varying a range of experimental parameters including the intensity, frequency and polarization of the pump light, the magnitude and orientation of the applied magnetic field, and the temperature and buffer gas pressure in the vapor cell. This investigation has confirmed important features of the mechanism, including the first observations of spontaneous polarization on the $F = 3 \rightarrow F = 3$ component (where the angular momentum is transferred by a slightly different mechanism, and is actually extracted from the buffer gas) and at high buffer gas pressures (up to 450 Torr at the time of writing). We have also developed a model of the phenomenon using numerical integration of the density matrix equations, which gives good qualitative and broad quantitative agreement with experimental data.

Experimental work currently under way is aimed at refining our understanding of this novel mechanism, including a more complete quantitative comparison with the model. There is also the prospect of observing spontaneous polarization for all angles of incident linear polarization relative to the applied field; this would open up the possibility of a precessing atomic polarization continually reinforced by isotropic unpolarized pump light. Progress will be reported at the conference; see also www.phys.washington.edu/~fortson/index.html.

[1] E. N. Fortson and B. R. Heckel, Phys. Rev. Lett. **59**, 1281 (1987).

[2] W. M. Klipstein, S. K. Lamoreaux, and E. N. Fortson, Phys. Rev. Lett. **76**, 2266 (1996).