Nonresonant spin echo in an ensemble of optically oriented atoms

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A spin echo in an ensemble of optically oriented atoms is obtained by switching on nonadiabatically a transverse magnetic field and then inverting it. The transverse relaxation time T_2 of cesium atoms in a Ne buffer gas is measured by using a nonresonance spin-echo technique.

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The spin echo, which was discovered by Hahn in 1950[5] and used widely in NMR and EPR spectroscopy, but has employed relatively recently in the field of optical orientation of atoms.[2-4] This effect was observed as a result of perturbing a system of magnetic moments in a constant nonuniform magnetic field by pulses of a variable magnetic field oscillating with a frequency of the magnetic resonance.

In this paper we obtained a spin echo for the first time in an ensemble of optically oriented atoms without using magnetic resonance. The experiment is as follows. Using

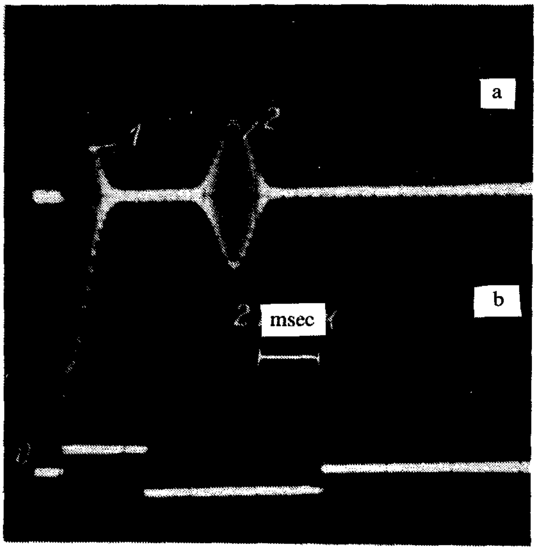

FIG. 1. (a) Signals of free precession (1) and of the spin echo (2) obtained by means of nonadiabatic switching on and single inversion of the transverse magnetic field $H_\perp = 0.015$ Oe; (b) oscillogram of the current that produces the transverse magnetic field.

a circularly polarized resonance optical radiation in an absorption cell, we produced a macroscopic magnetization of atoms directed along the pump light beam. After nonadiabatically rapid establishment of this magnetization, i.e., during the time

$$\tau_{\text{switching on}} << (\gamma H_\perp)^{-1} << \tau_2 = (T_2^{-1} + T_p)^{-1} \qquad (1)$$

the transverse (perpendicular to the pump light) magnetic field $\mathbf{H}_\perp$ is turned on: here γ is the gyromagnetic ratio of the investigated atoms and T_p is the optical relaxation time. In this case the net magnetic moment precesses around the field $\mathbf{H}_\perp$, which produced oscillations at the Larmor precession frequency in the absorption of the pump light by the cell.[5] Because of the nonuniform field $\mathbf{H}_\perp$, the magnetic moments corresponding to the different volume elements of the cell are dephased; this gives rise to a rapid damping of oscillations in the absorption of the pump light, with the time

$$T_2^* \sim (\gamma \Delta H_\perp)^{-1} < \tau_2 \qquad (2)$$

($\Delta H_\perp$ is the nonuniformity of the magnetic field in the cell). If this cell is inverted nonadiabatically at a time τ after the field $\mathbf{H}_\perp$ is turned on at $T_2^* < \tau < \tau_2$, then the magnetic moments will reverse the direction of their precession, and since the spatial distribution of the nonuniform field $\mathbf{H}_\perp$ does not change in the cell as a result of this inversion, and hence the frequencies of magnetic precession remain the same, the magnetic moments must be dephased at the time $t = 2\tau$ and the echo signal will appear. In the experiment this is manifested in the form of an oscillation pulse in the absorption of the pump light by the cell at the moment $t = 2\tau$.

Borcard *et al.*[6] observed a signal of nuclear spin echo without using a resonance pulsed rf field. To achieve this, they rapidly switched on a strong polarizing magnetic field directed perpendicular to the external, weak, nonuniform magnetic field.

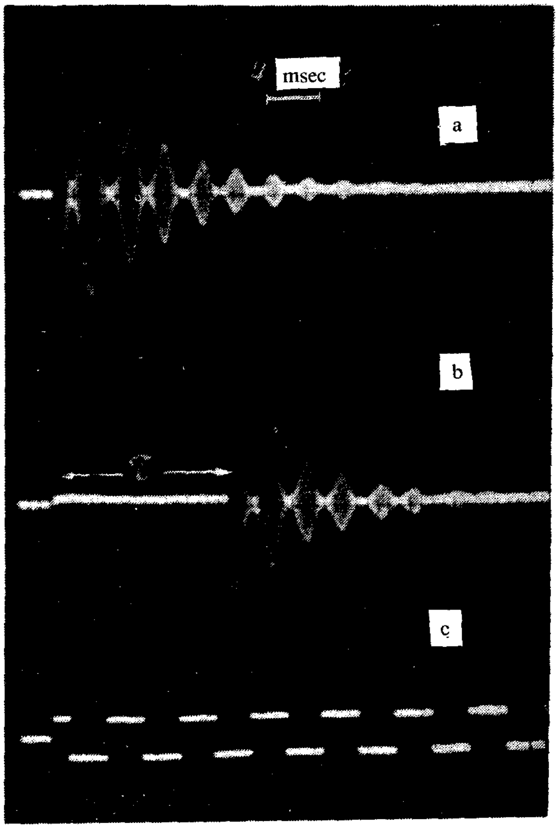

FIG. 2. A series of spin-echo signals, obtained by means of multiple inversion of the transverse magnetic field $H_\perp = 0.015$ Oe for (a) permanently turned on pump light, (b) fast switching off of the pump light for a time $\tau = 14$ msec, and (c) oscillogram of the current that produces the transverse magnetic field.

In our experiment we obtained a nonresonant spin echo in a system of optically oriented cesium atoms by placing into a magnetic shield a cesium pump tube, a circular polarizer, a cell containing cesium and Ne vapors at a pressure of 80 Torr, as well as a photoreceiver that recorded the variation of light intensity transmitted through the cell. The residual field in the shield was compensated for by a set of Helmholtz coils. To produce a transverse magnetic field with a controlled nonuniformity, we used a special pair of Helmholtz coils connected to a pulsed voltage supply. Figure 1(a) shows an oscillogram of signals from the photodetector, which was produced by switching on rapidly the transverse magnetic field and then inverting it once after the time $\tau = 2.6$ msec. As in the case of usual spin-echo method,[2] in the nonresonance method the amplitude of the echo decreased with increasing τ because of the thermal and optical relaxation and also because of diffusion of the optically oriented atoms.

Therefore, to measure the transverse relaxation time T_2, we repeatedly inverted the transverse magnetic field after it was turned on; this allowed us, like in the experiment of Carr and Purcell,[7] to substantially reduce the effect of diffusion on the amplitude of the echo. This is attributable to the fact that the contribution of the diffusion to attenuation of the echo signals depends on the time interval (τ_0) between the successive inversions of the transverse magnetic field and it can be made sufficiently small compared to T_2 by selecting $\tau_0 \ll T_2$. Thus, we can determine T_2 by measuring the effective times of the transverse relaxation τ_2 from the envelope of the echo amplitudes for different intensities of the pump light and by extrapolating τ_2^{-1} to zero light intensity.

Figure 2(a) shows an oscillogram of the spin-echo signals obtained by multiple inversion of the transverse magnetic field.

To avoid extrapolation to zero intensity of the pump light, we modified the experiment slightly; i.e., at the moment $\mathbf{H}_\perp$ was turned on, the pump light first was turned off and then quickly turned on at the instant of time corresponding to the maximum of one of the spin echoes in a series of echoes [Fig. 2(b)]. Changing the time the pump light was switched on and measuring the amplitude of the first echo signal observed after the pump light was turned on, we obtained an envelope of the echo amplitudes, which was free from optical relaxation. Moreover, in order to completely eliminate the contribution of diffusion to the attenuation time (T_{dark}) of the echo signals measured in this manner, we measured T_{dark} for different intervals of time τ_0 between the successive inversions of the transverse magnetic field and then determined the time T_2 by extrapolating the measured values of T_{dark} to zero time τ_0.

The transverse relaxation time for our cell (Ne, 80 Torr), which was measured by using this technique, is $T_2 = 46$ msec.

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