Polarization properties of the modified stimulated photon echo in ytterbium vapor

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Keller and Le Gouët's experiment on the modified stimulated photon echo in ytterbium vapor is explained. The photon-echo method has been used for the first time to obtain information on the alignment relaxation time. There is a way to alter the experimental conditions in order to determine the orientation relaxation time.

The modified stimulated photon echo in a gaseous medium is formed by the application of three exciting pulses. The first two have a carrier frequency ω_1, which is at resonance with the frequency of an optically allowed transition $b \rightarrow a$. The third has a carrier frequency ω_2, which is at resonance with the frequency of the optically allowed transition $c \rightarrow b$ $(E_a < E_b < E_c)$. If these exciting pulses propagate through the medium under study in a common direction, the modified stimulated photon echo signal, which is formed at approximately the time $\tau_2 + (1 + \omega_1/\omega_2)\tau_1$, propagates in the same direction with a carrier frequency ω_2 (see Ref. 1, for example). Here τ_1 (τ_2) is the time interval between the first and second (second and third) exciting pulses.

In recent experiments, Keller and Le Gouët[2] observed the modified stimulated photon echo in ^{174}Yb vapor by working with transitions with resonant levels having angular momenta $J_a = 0$ and $J_b = J_c = 1$. Keller and Le Gouët[2] found that the ratio (η) of the intensity of the modified stimulated photon echo in the case in which all the exciting pulses are polarized in a common plane to the intensity of this echo in the case in which the first two exciting pulses are polarized orthogonal to the third is about 2×10^{-3}. This fact was not interpreted in Ref. 2. We note that the areas under the exciting pulses in Ref. 2 cannot, in general, be regarded as small.

The idea of using the modified stimulated photon echo to measure the relaxation times of the population $(1/\gamma_b^{(0)})$, the orientation $(1/\gamma_b^{(1)}$; the decay time for the magnetic moment), and the alignment $(1/\gamma_b^{(2)}$; the decay time of the quadrupole moment) of the common level b was originally proposed in Refs. 1 and 3. The idea was to choose the angles ψ_1 and ψ_2 (between the polarization vectors of the exciting pulses) appropriately and to study the decay of the projections of the electric field of the modified stimulated photon echo as the time interval (τ_2) between the second and third exciting pulses was increased. Here ψ_1 (ψ_2) is the angle between the polarization vectors of the first and third (second and third) exciting pulses. We wish to emphasize that the calculations in Refs. 1 and 3 were carried out for arbitrary angular momenta of the resonant levels, but for small areas under the exciting pulses.

Nevertheless, the equations derived in Ref. 1 make it a simple matter to interpret the experimental results of Ref. 2. In the first place, it follows from Ref. 1 that for transitions with resonant levels having angular momenta $J_a = 0$ and $J_b = J_c = 1$, in cases in which all the exciting pulses are polarized in a common plane $(\psi_1 = \psi_2 = 0)$ or when the polarization of the first two exciting pulses is orthogonal to that of the third

($\psi_1 = \psi_2 = \pi/2$), the modified stimulated photon echo will be polarized along the polarization vector of the third exciting pulses. This result agrees with the experimental results in Ref. 2. Second, the ratio of the intensities of the echo in these two cases is

$$\eta = \{1 - \exp[-(\gamma_b^{(2)} - \gamma_b^{(0)})\tau_2]\}^2 \left\{1 + \frac{1}{2}\exp[-(\gamma_b^{(2)} - \gamma_b^{(0)})\tau_2]\right\}^{-2} . \quad (1)$$

We know that the difference $\gamma_b^{(2)} - \gamma_b^{(0)}$ is caused entirely be depolarizing elastic collisions, and it is quite small at the low pressures in the experiments of Ref. 2. This fact explains the small value of η found in the experiments of Ref. 2, as can be seen from expression (1). However, expression (1), which follows from Ref. 1, refers to the case in which the areas under the exciting pulses are small, while in the experiments of Ref. 2 these areas were generally not small. We have accordingly calculated the modified stimulated photon echo signal for transitions with resonant levels having angular momenta $J_a = 0$ and $J_b = J_c = 1$, in accordance with the experiments of Ref. 2, for arbitrary areas under the exciting pulses.

It turns out that for the relative orientations of the polarization vectors of the exciting pulses in the experiments of Ref. 2 ($\psi_1 = \psi_2 = 0$ and $\psi_1 = \psi_2 = \pi/2$) the direction of the polarization vector of the echo and the ratio in (1) will be independent of the areas under these pulses. The same conclusion—that these areas are irrelevant—is drawn for two other cases of the relative orientations of the polarization vectors of the exciting pulses: $\psi_1 = \pi/2$, $\psi_2 = 0$ and $\psi_1 = 0$, $\psi_2 = \pi/2$. For these cases, the ratio (ξ) of the intensities of the modified stimulated photon echo is

$$\xi = \{1 - \exp[-(\gamma_b^{(1)} - \gamma_b^{(2)})\tau_2]\}^2 \{1 + \exp[-(\gamma_b^{(1)} - \gamma_b^{(2)})\tau_2]\}^{-2} , \quad (2)$$

and the polarization vector of the echo is orthogonal to that of the third exciting pulse.

Expressions (1) and (2) give us a method, different from that proposed in Refs. 1 and 3, for finding the alignment and orientation relaxation times when the population relaxation time is known. Here we should study the growth of the ratios η and ξ with increasing value of time interval (τ_2) between the second and third exciting pulses. This method has a definite advantage, since any deviation of these ratios from zero results from the differences $\gamma_b^{(2)} - \gamma_b^{(0)}$ and $\gamma_b^{(2)} - \gamma_b^{(1)}$. A simultaneous determination of $\gamma_b^{(2)}$ and $\gamma_b^{(1)}$ would make it possible to test the theoretical predictions regarding the ratio $(\gamma_b^{(1)} - \gamma_b^{(0)})/(\gamma_b^{(2)} - \gamma_b^{(0)})$, which should have the value 1.13 if the interaction between the resonant atoms and the buffer-gas atoms is a van der Waals interaction.[4]

Unfortunately, the experiments in Ref. 2 were carried out only for the cases of $\psi_1 = \psi_2 = 0$ and $\psi_1 = \psi_2 = \pi/2$, so we can use only expression (1) to find a value for $\gamma_b^{(2)}$. Taking the experimental value of 2×10^{-3} for η, and setting τ_2 equal to 75 ns (τ_2 was varied over the interval from 60 to 90 ns in Ref. 2), we find the difference $\gamma_b^{(2)} - \gamma_b^{(0)}$ to be $0.9\times10^6\ \mathrm{s}^{-1}$. Using the lifetime $1/\gamma_b^{(0)} = 875$ ns given for level b in Ref. 2, we find the relaxation characteristic to be $\gamma_b^{(2)} \cong 2.05\times10^6\ \mathrm{s}^{-1}$.

Although the possibility of extracting values of $\gamma_b^{(\kappa)}$ ($\kappa\neq0$) from experiments on the modified stimulated photon echo has been discussed in the literature,[1,3] there has been no previous determination of a concrete value for the alignment relaxation time of a resonant level.

We note in conclusion that it would apparently be possible to carry out experiments for cases in which the relative orientations of the polarization vectors of the exciting pulses are $\psi_1 = \pi/2$, $\psi_2 = 0$ and $\psi_1 = 0$, $\psi_2 = \pi/2$. Such experiments would make it possible, with the help of (2) and the known value of $\gamma_b^{(2)}$, to find the relaxation characteristic $\gamma_b^{(1)}$.

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