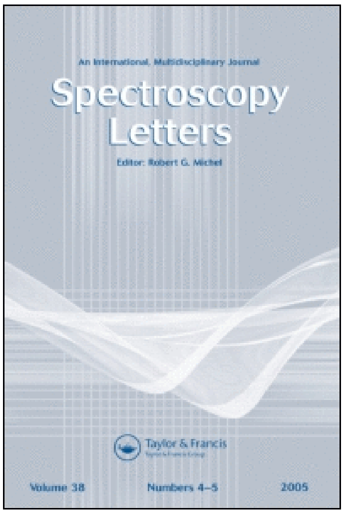

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Dependence of the Relaxation Signal of an Optically Pumped Vapor on the Detection Beam Radius: An Experimental Test

E. Bernabeu[a,b]; J. Tornos[a]
[a] Departamento de Optica, Universidad de Zaragoza, Zaragoza, Spain [b] Departamento de Física Fundamental, Universidad Autónoma de Barcelo na, Barcelona, Spain

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DEPENDENCE OF THE RELAXATION SIGNAL OF AN OPTICALLY PUMPED VAPOR ON THE DETECTION BEAM RADIUS: AN EXPERIMENTAL TEST

E. Bernabeu* and J. Tornos

Departamento de Optica. Universidad de Zaragoza.
Zaragoza, Spain.

An experimental verification of the dependence of the relaxation signal shape of an optically pumped vapor contained in an spherical cell on the radius of the cylindrical detection beam is presented.

The relaxation signal of an optically pumped alkali vapor in the presence of a buffer gas may be described in general as a superposition of several infinite series of exponential terms. The amplitude of these terms (diffusion modes) decreases quickly with the series index , so that each one of these series is usually approximated by its dominant mode (Franzen's approximation)[1]. This approximation may lead to non negligible systematic errors in the determination of the characteristic parameters in optical pumping experiments: diffusion coefficient and relaxation cross sections by alkali-alkali and alkali-gas collisions[2,3].

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* Departamento de Física Fundamental. Universidad Autónoma de Barcelona. Bellaterra (Barcelona). Spain.

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In a recent paper[4] we have studied the dependence of the amplitudes of the most important diffusion modes on several experimental factors. For the case of spherical cells we obtained that the amplitude of the second most important mode vanishes when the detection beam radius is 0.54 times the one of the cell. This simple experimental condition permits the minimization of the errors introduced by Franzen's approximation.

In the present paper we report on an experimental checking of our previous results about the dependence of the contribution of the most important diffusion modes to the relaxation signal on the radius of the cylindrical detection beam.

We have measured the $\langle S_z \rangle$ relaxation transients of optically pumped cesium vapor in the presence of 10 torr nytrogen, at 298 K and contained in a spherical cell of R = 2.5 cm. The experimental set up has been the usual one for the generation and detection of $\langle S_z \rangle$ (fig. 1), with a quasicylindrical detection beam whose radius αR can be ad-

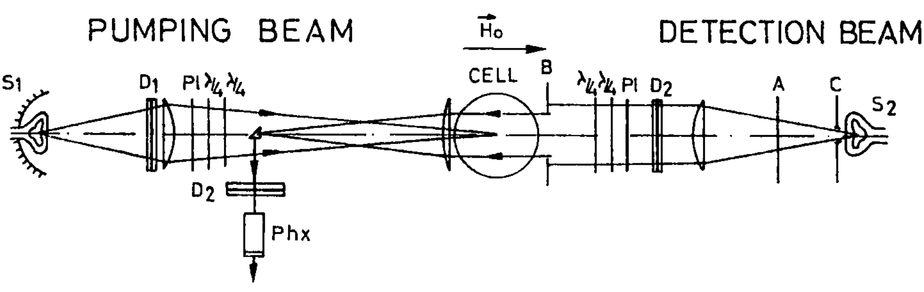

Fig. 1.- Experimental set-up: Cs lamps (S_1, S_2), circular polarizers (LP = linear polarizer, $\lambda/4$ = quarter wavelength plate), interference filters (D_1, D_2), photomultiplier (Phx), neutral filter (A), iris diaphragm (C), small diaphragm (B).

justed; this requiring one lens after the cell in order to focus the beam on the detector.

S_z is a linear combination of the two dipole eigenobservables that relax uncoupled with other multipole orders in the limit of weak orientation of the atomic vapor.

So, the relaxation of $\langle S_z \rangle$ in this limit is the sum of two series of exponential terms

$$\langle S_z \rangle (t) = A^{(1)} \sum_{\nu,l} P^{(1)}_{\nu,l} \exp\{-t/\tau^{(1)}_{\nu,l}\} + A^{(2)} \sum_{\nu,l} P^{(2)}_{\nu,l} \exp\{-t/\tau^{(2)}_{\nu,l}\} ,$$

where $\nu = 1, 2, 3, \ldots ; l = 0, 2, 4, \ldots,$

with time constants approximately given for cesium vapor by[5]

$$1/\tau^{(1)}_{\nu,l} = (1/T_{\nu,l}) + (1/32T_e) + (1/32T_s) ,$$

$$1/\tau^{(2)}_{\nu,l} = (1/T_{\nu,l}) + (1/T_e) + (21/32T_s) ,$$

where T_s and T_e are the characteristic relaxation times for alkali-alkali (spin-exchange) and alkali-gas collisions respectively, and $T_{\nu,l}$ are the relaxation times for collisions against the cell walls after the diffusion process, common to the two eigenobservables.

If Franzen's approximation is assumed, the $\langle S_z \rangle$ relaxation signal must be fitted to the sum of two exponentials that are assigned to the $(\nu,l) = (1,0)$ modes. The errors introduced by this approximation are minimized when the detection is performed with a cylindrical beam with $\alpha = 0.54$. For other α values a non negligible contribution of (2,0) modes (which are the most competitive against the dominant ones) appears, and a variation in the relaxation signal shape is expected.

In a first stage the $\langle S_z \rangle$ relaxation signal has been measured with $\alpha = 0.54$. The fitting of this signal to two exponentials is shown in Fig. 2. Starting from the fitted time constants of these exponentials and taking into account the T_S value for cesium vapor[(6)] we can obtain the time constants of the (2,0) modes. With these values and our previous results about the dependence of the relative amplitudes of the first diffusion modes on the detector beam radius (see Fig. 3 of ref. 4) we can also obtain the absolute amplitudes of (2,0) modes for any α value. In short, starting from the measured signal for $\alpha = 0.54$ we can construct the shape of the expected relaxa-

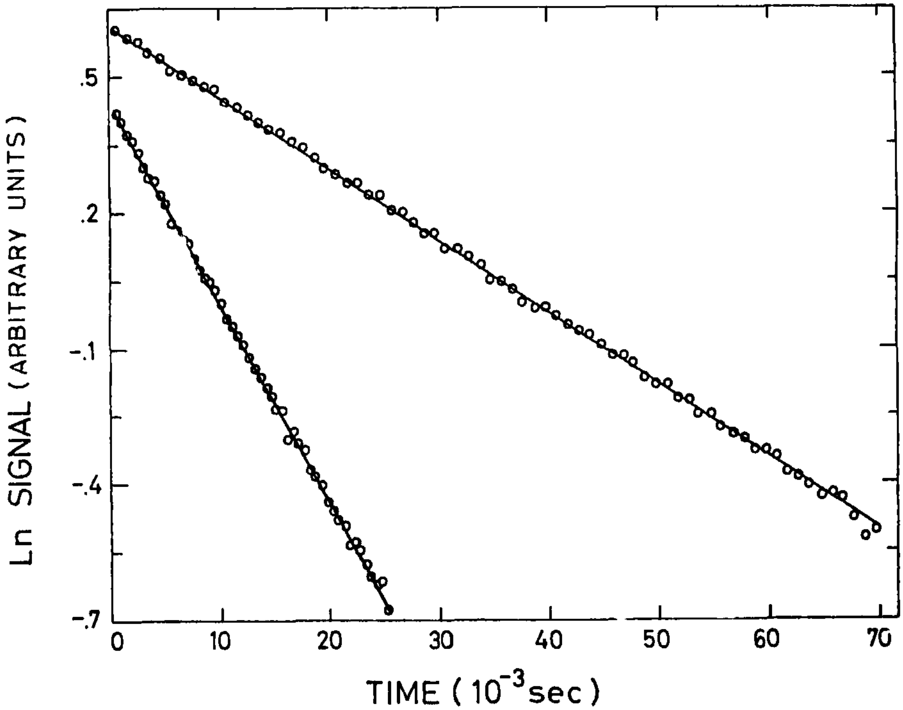

Fig. 2.- Fit to two exponential terms of the signal measured for $\alpha = 0.54$.

tion signal for any α value. A comparison between theory and experience is then possible, checking our previous results of ref. 4.

In Fig. 2 we show the good agreement between theoretical and experimental signals that we have obtained for $\alpha = 0.4$ and $\alpha = 0.7$; in all the signals the contribution of the dominant mode $(1,0)_{(1)}$ fitted for $\alpha = 0.54$ has been substracted for a better visualization. In order to make a comparison among the relaxation signals for different values of α, the experimental signals have been normalized to a common value in a moment far enough after the beginning of the relaxation process, so that the (2,0) modes, which have the shortest time constants, may be considered as relaxed.

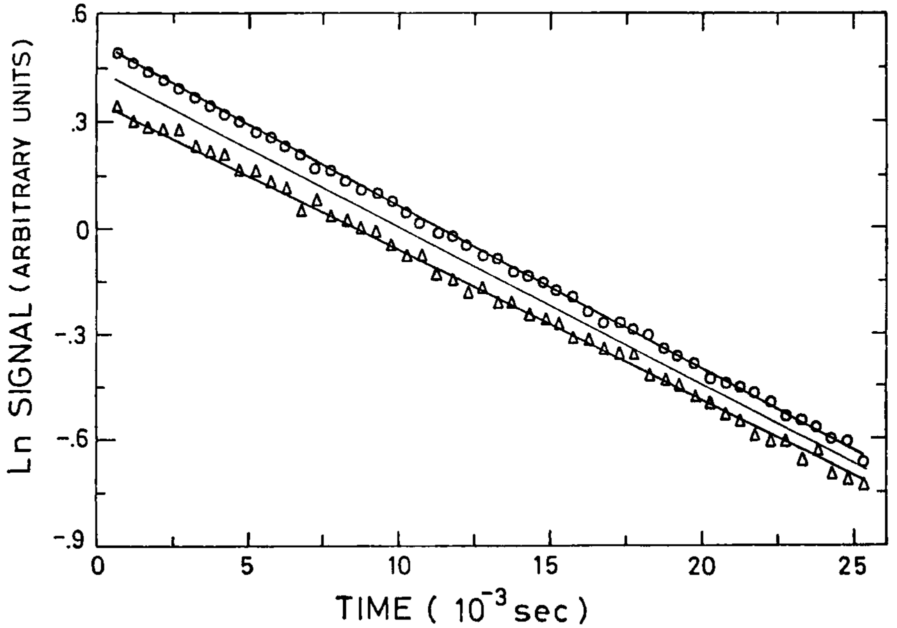

Fig. 3.- Theoretical (solid lines) and experimental signals for α = 0.4 (triangles) and $\alpha = 0.7$ (circles). The intermediate solid line corresponds to $\alpha = 0.54$. The dominant exponential fitted for $\alpha = 0.54$ has been substracted in all signals.

In our experimental set up the spatial distribution of intensity in the pumping beam was approximately gaussian, with a width close to the limit that permits the neglecting of the contribution of the (1,2) modes to the relaxation signal. Because of this we have neglected these contributions against the ones of the (1,0) modes in the fitting of the experimental signal for $\alpha = 0.54$, but we have taken into account their variations with α, non negligible in comparison with the (2,0) modes, for the construction of the theoretical signal for other α values. The variations with α of the contributions of the (1,2) modes are calculable in the way explained for the (2,0) modes, starting from the measured signal for $\alpha = 0.54$.

Notice that when one fits the signals measured with $\alpha = 0.4$ or $\alpha = 0.7$ to two exponentials (Franzen's approximation) the fitted value of the time constant for the fast decreasing exponential differs in a non negligible amount (~ ± 5%) from the one fitted with $\alpha = 0.54$. In conclusion, appreciable systematic errors may be expected in the determination of the characteristic relaxation parameters, as we show in ref. 3. These errors may be avoided to a large extent if one works under the experimental conditions we have just shown.

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