Effects of size and dimension in optic relaxation in Rb vapor

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Abstract. We report on an experiment in which the fluorescence decay time of 5P levels of Rb atoms in a coated vapor cell exceeds several of milliseconds that many orders of magnitude longer than normal decay time of excited of rubidium atoms. This effect has been observed by using the pump laser with fixing frequency and the periodically scan the probing laser frequency of which overlap all Rb hyperfine linens of 5P-5S transition. Long time fluorescence decay take place in wide part of the spherical high quality coated cell. In cylindrical part of the cell or in uncoated cell the long time fluorescence decay was disappeared.

The study of the optical properties of rubidium vapors has recently acquired considerable relevance due to the prospects for creating precision atomic time standards [1-3], as well as other quantum devices using long-lived polarized states of rubidium atoms [4, 5]. In order to increase the lifetime of polarized states, which can be destroyed in collisions of atoms with the walls of the cell, various antirelaxation coatings based on saturated hydrocarbons are used: paraffin, ceresin [6]. Recently, coatings have been discovered that further increase the lifetime of polarized states of alkali metals based on high molecular weight alkenes - hydrocarbons with one double bond.

When creating an atomic clock, both the method of double radio-optical resonance and bichromatic laser radiation can be used. Under certain conditions, bichromatic laser radiation is capable of creating a coherent population trapping (CPT) resonance [7-9] between the ground state sublevels, split due to the interaction of the nuclear spin with the orbital moments and electron spin. The main condition for CPT resonance is the coincidence of the frequency difference of the bichromatic laser radiation with the hyperfine splitting of the ground state, which is the frequency reference for atomic frequencies. A CPT resonance is observed by the phenomenon of induced optical transparency, since CPT produces a coherent superposition of hyperfine sublevels of the ground state that does not interact with bichromatic laser radiation.

Of interest are other aspects of such interaction without the purposeful creation of a CPT. Earlier in [10], a long decay of the fluorescence of rubidium vapor in a spherical cell of a special design with a ceresin coating, which does not have a source of rubidium vapor with a free metal surface, was found [11]. In [10], one sufficiently intense laser pumping radiation had a fixed frequency, resonant to one of the transitions between the hyperfine components of the ground state (5^2S_{1/2}) and the excited state (5^2P_{1/2,3/2}^2P_{1/2}) in a natural mixture of ^85Rb and ^87Rb vapors. The second intense probe laser radiation was frequency modulated according to a triangular law. The frequency modulation range was about 9 GHz, overlapping the spectral interval in which all allowed electric dipole transitions between the hyperfine sublevels of the 5^2P_{1/2} and 5^2S_{1/2} states are located. The frequency modulation period could be adjusted from 3 to 10 milliseconds. The long decay of the fluorescence of rubidium vapor was superimposed on the fluorescence spectrum and started at the time when the pump and probe radiation were in resonance with the three-level A level scheme, with the upper 5^2P_{1/2} state and the lower levels formed due to hyperfine splitting of the ground state.

In this paper, we present the results of a series of experiments similar to [10], but carried out with different configurations of laser beams with respect to the cell. The pump laser radiation frequency was chosen to be resonant to the 5^2P_{1/2}^-5^2S_{1/2} (F = 3) transition of the ^85Rb isotope. Figure 1a shows a scheme for measuring the fluorescence signal, in which the cell with rubidium vapor consists of a spherical part 12 cm in diameter and a relatively thin tube 8 mm in diameter and 10 cm long. The cell
is covered with ceresin from the inside. A piece of metallic rubidium is placed at the end of the tube farthest from the ball. The pump radiation propagates from right to left from the side of the ball. Probing radiation propagates in parallel to the pump radiation and towards it. The graphs of the fluorescence signal depending on the observation time associated with the frequency of the probe radiation with frequency modulation according to the triangular law for two registration zones are shown in figure 1b. In fact, figure 1b shows the fluorescence plots for half the period of frequency modulation of the probe radiation. The capillary zone (zone 1 in figure 1a) corresponds to graph 1 in figure 1b. For the center of the spherical part (zone 2 in figure 1a), the fluorescence signal is shown in graph 2 in figure 1b.

![Figure 1a](image1a.png)

**Figure 1a.** A scheme for measuring the fluorescence signal (a), fluorescence signal from registration zones 1 and 2 of the cell.

![Figure 1b](image1b.png)

**Figure 1b.** A scheme for measuring the fluorescence signal (b).

The fluorescence peaks in the region of the capillary 1 reproduce the shape of the absorption lines taking into account the optical pumping for each of the rubidium isotopes. In the center of the spherical part of the cuvette, the time dependence of the fluorescence signal is qualitatively different (graph 2 in figure 1b). In addition to the fluorescence peaks associated with the shape of the absorption lines, a slowly decaying fluorescence signal is clearly observed when the probe radiation has ceased to
be resonant to the \(5^2P_{1/2} - 5^2S_{1/2}\) (\(F = 3\)) transition of the \(^{85}\text{Rb}\) isotope, starting from the time interval 0.006 sec. In addition, a permanent backing appears in the fluorescence signal, which is apparently associated with the overlapping of slowly decaying fluorescence signals from different periods of frequency modulation of the probe radiation. Those, the slowly decaying fluorescence signal starts when the probe radiation is resonant with the \(5^2P_{1/2} - 5^2S_{1/2}\) (\(F = 2\)) transition of the \(^{85}\text{Rb}\) isotope and lasts much longer than the half-period of frequency modulation, the duration of which in this experiment is about 0.012 sec. Graphs ha fig. 1b have truncated tops due to saturation of the recording system, the gain in which was increased in order to emphasize the amplitude of the slowly decaying fluorescence signal.

The fluorescence spectrum of zone 2 (graph 3 in figure 2b) with a closed pump beam represents four weak, at the level of noise, peaks characteristic of the absorption spectrum of rubidium isotopes, which appeared, apparently, from the action of the residual scattered probe radiation. The same mechanism of the appearance of weak peaks outside the zone of action of the probe radiation is also manifested in graph 2 in figure 2b. Graphs 1 to 3 in figure 2b are spaced vertically to better distinguish the spectral-temporal features of the fluorescence signal of rubidium isotopes.

\[\text{Graph 1 to 3 in figure 2b are spaced vertically to better distinguish the spectral-temporal features of the fluorescence signal of rubidium isotopes.}\]

Figure 2. Fluorescence signal from registration zones 1 and 2 of the cell (b) with oblique propagation of the probe laser beam and the pump beam (a). Frequency scale is the same as in figure 1.
The experimental results demonstrate the dependence of the dynamics of relaxation processes in rubidium vapor on the size and dimension from registration scheme of the fluorescence signal. In the one-dimensional case (figure 1, registration zone 1), long decay time of the fluorescence is not observed. The growth of the decay time of fluorescence can be used as the basis for a simple method for determining the quality of the coating of the cells.

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