Self-contraction of laser pulses in molecular rubidium vapor

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A temporary self-contraction of short and powerful ruby-laser pulses were observed as they passed resonantly through Rb_2 vapor. The conditions for the appearance of the pulse self-contraction effects and for the bleaching of the Rb_2 vapor are investigated.

We report here experimental observation of the effect of self-contraction of short and high-power ruby-laser pulses as they pass resonantly through Rb_2 vapor, and the conditions for the appearance of this effect. The prospects of attaining self-contraction of laser pulses in alkali-metal vapors were pointed out by Zel'dovich and Sobel'man. The features of resonant passage of laser pulses through Rb_2 vapor under certain conditions were investigated in[2,3]. The conditions and the features of the appearance of the self-contraction effect in this resonant medium complement significantly these researches. Figure 1 shows an oscillogram of the pulses observed in the present experiment. The signal on the right is the pulse passing through a cell with Rb_2 vapor, and on the left is the output pulse. As seen from Fig. 1. The pulse assumes after passing through the cell with Rb_2 vapor a symmetrical regular form and is much shorter in duration (by an approximate factor 2.5 than the input pulse). The laser pulse entering the cell (110 cm long) had a duration 17—20 nsec at $\sim 10^5$—10^6 W/cm^2. The vapor temperature could be regulated continuously between room temperature and 350°C. The pulses passing through the cell and bypassing the cell were recorded with a high-speed ELU-FT photomultiplier having a time resolution not worse than 2.7×10^{-9} sec. A little information concerning the resonant system.[2,3] The resonant absorption and emission occur in the $^1\Sigma_g^+ - {}^1\Pi_u^+$ band. The excitation was at 6943 Å on the transitions $v''=5-10 \rightarrow v'=2-7$. The radiative relaxation time T_r of the excited levels was $(19-25)\times10^{-9}$ sec. The time of the irreversible relaxation due to the molecule-molecule and molecule-atom collisions was temperature dependent and was not shorter than T_r under the conditions of our experiments (thus, the time of the relaxation due to the resonant interaction of the molecules was 7×10^{-8} sec). The pulse duration was therefore shorter than the irreversible relaxation times. On the other hand, the inhomogeneous line width due to the

FIG. 1. Oscillogram of the pulses at the entrance (left) and exits (right) of a cell with Rb_2 vapor.

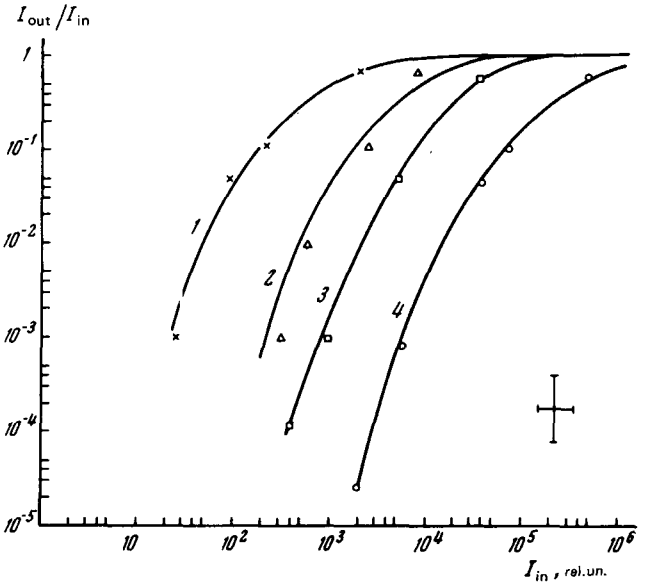

FIG. 2. Experimental plot of I_{out}/I_{in} against I_{in} at various temperatures: 1- 222°C, 2- 230°C, 3- 235°C, 4- 248°C.

Doppler effect depends on the temperature and reaches 2.5×10^8 and 4×10^8 sec^{-1} at 300°K and 540°K, respectively. Consequently, only a fraction of the molecules (1/4—1/6) takes part in the resonant absorption and emission under the conditions of our experiment. It is typical that when the pulse moves towards the end of the cell, practically the entire inhomogeneously-broadened line is excited, owing to the narrowing of the pulse.

The investigations of[2] point out one more reason for the possible bleaching, namely the dissociation of the rubidium molecules into atoms at laser pulse powers $\geq 10^7$ W/cm^2. Thus, the effect of dissociation on the pulse deformation process[4] and on the possible bleaching of the medium is negligible in our experiment. Such bleaching, as follows from the experimentally obtained plots of I_{out}/I_{in} against I_{in} (Fig. 2, where I_{in} and I_{out} are the laser pulse intensities on entering and leaving the cell), did indeed take place. We note that a similar behavior was observed also in the experiments of[5,6], where the inflection point (I_{inf}) corresponded to a π pulse. At intensities $I_{in} < I_{inf}$ the pulse is absorbed in accord with the Bouguer-Beer law, and at $I_{in} > I_{inf}$ the medium becomes bleached.

We call attention to one more feature of a self-contracting pulse. In a resonant medium it is delayed in time and acquires a characteristic stationary shape described by a near-Gaussian curve. We recall that the well known solution of the area theorem, obtained by McCall and Hahn[7] for samples of infinite length, yields for the stationary pulse a shape given by $\mathrm{sech}[(t-l/c)/\Delta t]$ (where Δt is the pulse duration, c is the pulse velocity in the medium, and l is the length of the cell), which differs from Gaussian mainly in that the wings are drawn tighter. All this gives grounds for assuming that a stationary 2π pulse is produced in the Rb_2 vapor under the considered conditions.[1,7] The energy loss to nonresonant absorption is estimated from the formula $I_{out} = I_{in}\exp(-\alpha l)$, where α is the coefficient of nonresonant absorption, which we have obtained experimentally and which depends on the excitation condition. Its values can be found from the plots in Fig. 2. The foregoing makes it possible to estimate the modulus of the electric dipole moment of the transition, $p \approx (2\pi\hbar/\Delta t_{out})(4\pi I_{out}/c)^{1/2}$, which equals $(3—5)\times10^{-1}$ cgs esu.

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