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RESONANCE FLUORESCENCE OF AN ATOMIC BEAM AT SATURATED EXCITATION OF CASCADE LEVELS

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НОВОСИБИРСК

РЕЗОНАНСНАЯ ФЛУОРЕСЦЕНЦИЯ ПРИ КАСКАДНОМ НАСЫЩЕННОМ ВОЗБУЖДЕНИИ АТОМНЫХ ПУЧКОВ

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А Н Н О Т А Ц И Я

Настоящая работа представлена на 9 Европейскую конференцию по атомной и молекулярной физике ионизованных газов, Лиссабон, 1988. В работе проанализирована динамика распространения резонансной флуоресценции в потоке атомов при возбуждении трехуровневой системы двумя интенсивными лазерными пучками. Показано, что при достаточно большой скорости потока атомов спонтанное излучение с верхнего уровня может беспрепятственно распространяться в направлении, противоположном движению пучка, при любой плотности атомов. Приведены соответствующие оценки для случая плотного литиевого пучка.

RESONANCE FLUORESCENCE OF AN ATOMIC BEAM AT SATURATED EXCITATION OF CASCADE LEVELS

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Laser induced fluorescence of an atomic beam is successfully used as a diagnostic technique. In recent years there have been several investigations when the optical double resonance in atomic beams was used for this purpose [1—4]. On many occasions a beam density can be sufficiently high. In this paper we study the problem of passing the resonance fluorescence from the excited volume L to a detecting system through the surrounding atomic flow.

We introduce the model of a three-level atomic system shown in Fig. 1. The levels 1, 2, 3 are coupled by intense laser radiations with wavelengths λ_1 and λ_2.

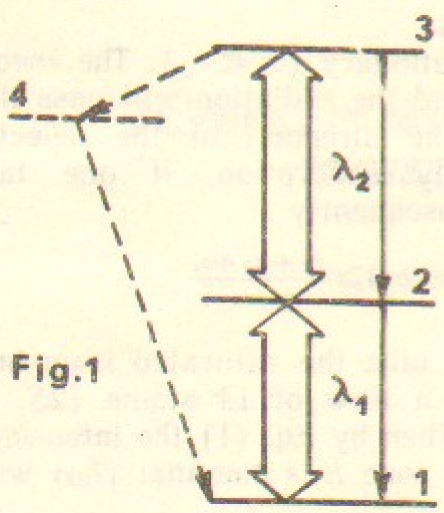

Fig.1

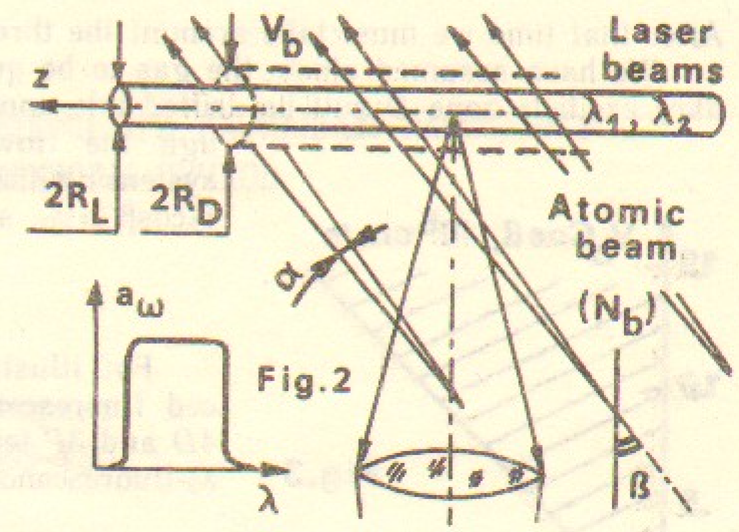

Fig.2

The spectral widths of these radiations are more than the Doppler width of the absorption lines. The Doppler width is caused by the angular spread of the atomic beam and the distribution in energy of the beam atoms. In the general case, the spectral lines can be spatially nonisotropic, but, as a rule, they have no wings. Further we assume a rectangular isotropic shape of the lines a_ω (Fig. 2) with a width $\Delta\omega_i = 2\pi\alpha v_b/\lambda_i$. In this case, the diffusive mechanism of radiation transfer in a gas is realized [5]. The typical scheme of resonance fluorescence experiments is shown in Fig. 2. Two intense beams of pulse lasers excite the atoms of a broad atomic flow into volume L in the saturation regime. The intensity of spontaneous emission from the upper level (λ_2) is recorded with a detecting system. The intensity grows with the flow density and tends to its maximum value $I_{02}(cm^{-1}s^{-1}) = \Delta\omega_2/\lambda_2^2$ when the free path length l_{2L} becomes less than a radius of the excited volume[1]:

$$l_{2L} = \frac{4(g_1+g_2+g_3)}{g_3} \cdot \frac{\Delta\omega_2}{\lambda_2^2 A_{32} N_b} \leqslant R_L . \qquad (1)$$

[1] If a system is four-level (e. g. Li-atom), the summand g_3 will be replaced by $g_3(1+A_{34}/A_{41})$.

At the pulse beginning the surrounding gas is transparent for λ_2 radiation, but in the course of time the emission flow $I_{01} = \Delta\omega_1/\lambda_1^2$, which is emitted from zone L, excites the middle level of the atoms in the zone D. This zone becomes nontransparent for λ_2-radiation at the moment of time $t = T$. Before this moment only a simple two-level system 1-2 can by taken into account. The path length $l_0 = (\sigma_{12} N_b)^{-1} = 4(g_1/g_2)(\Delta\omega_1/A_{21}\lambda_1^2 N_b)$ is small, and the radiation flow I_{01} is high enough in order to excite the second level up to saturation: $n_2^{sat} = g_2 N_b/(g_1 + g_2)$. It means that zone D expands as «a wave of self-induced transparency». The expansion velocity and the boundary position are

$$v_D \simeq \frac{g_1+g_2}{4g_1}\frac{R_L}{R_D} l_0 A_{21}, \quad R_D(t) - R_L = R_L\left(\sqrt{1 + \frac{g_1+g_2}{2g_1} A_{21}\frac{l_0}{R_L} t} - 1\right) \qquad (2)$$

When the absorption coeffcient $n_2^{sat}(R_D - R_L)\sigma_{23}$ becomes equal to 1, the radiation λ_2 will be absorbed into zone D. Thus, the absorption becomes a factor when

$$t \geqslant T = \frac{2g_2}{g_3}\left(\frac{\lambda_1}{\lambda_2}\right)^3\left(2 + \frac{l_{2D}}{R_L}\right) A_{32}^{-1}, \quad l_{2D} = \frac{(g_1+g_2) l_{2L}}{g_1+g_2+g_3}. \qquad (3)$$

After that time we must take account the three levels.

We have assumed above the gas to be quasi-stationary ($v_b \ll v_D$). The «secondary excited» zone D will be drifted into zone L, and the radiation will pass through the flow in the direction of the detecting system without any absorption, if one takes $v_b \cos\beta \geqslant v_D$, and consequently

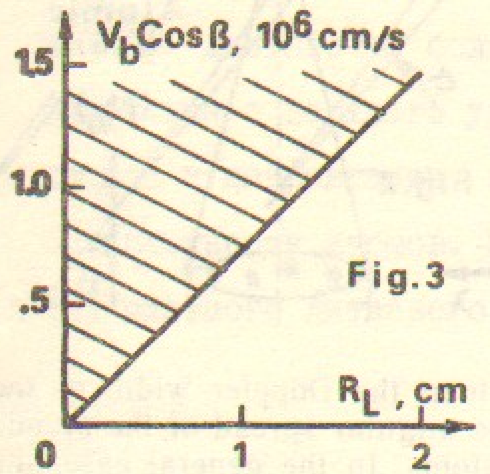

Fig.3

$$N_b v_b \cos\beta \geqslant \frac{g_1+g_2}{g_2}\frac{\Delta\omega_1}{\lambda_1^2}. \qquad (4)$$

For illustration, take the saturated laser-induced fluorescence of a flow of Li atoms ($2S$, $2P$, $4D$ and $3P$ levels), then by Eq. (1) the intensity of λ_2-fluorescence from zone L is maximal (I_{02}) when

$$N_{bm} \equiv N_b|_{2L = R_L} = \frac{4[g_1 + g_2 + g_3(1 + A_{34}/A_{41})]}{g_3} \cdot \frac{\Delta\omega_2}{\lambda_2^2 A_{32} R_L}. \qquad (5)$$

Substitute N_{bm} in Eq. (4) and obtain a domain where conditions (4) and (5) are both satisfied (see the cross-hatched field in the Fig. 3). Let $\alpha = 5\cdot10^{-3}$, $v_b \mathrm{Cos}\beta = 0.7\cdot10^5$ cm/s, and $R_L = 0.5$mm [3], then $N_{bm} = 2\cdot10^{12}$ cm^{-3} and the condition (4) is satisfied ($N > 2\cdot10^{11}$ cm^{-3}).

Thus, the saturated resonance fluorescence from the upper level can be observed without absorption even at very high density of an atomic beam, if the beam velocity is high sufficiently.

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