ON THE INTERACTION OF AN ULTRASHORT LIGHT PULSE WITH A THIN RESONANT MEDIUM II

By

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An optically thin, two level atomic system interacts with a pulse of resonant electromagnetic field. The effects of relaxation on the transmitted and reflected waves are investigated. As a general rule damping of the polarization reduces reflexion and strengthens the transmission.

In a previous paper [1] we have investigated the transmission and reflexion in the resonant interaction of an ultrashort light pulse with a thin film, containing two level atoms. In this paper we report results for a model including damping as well.

The interaction is described by the modified Bloch equations [1, 2, 3] as

$$\dot{v}=(\mathscr{E}+v)w-\gamma_{\perp}v; \quad \dot{w}=-(\mathscr{E}+v)v-\gamma_{\parallel}((w+1), \tag{1a, b}$$

where the damping of the polarization and of the inversion have been introduced. The coefficient $\gamma_{\parallel}$ of the damping of the inversion is usually much less than that of the polarization, $\gamma_{\parallel}\ll\gamma_{\perp}$ and we can simply set $\gamma_{\parallel}=0$. In the case of exact resonance the Bloch vector component v characterizes the polarization, and w is the difference between the populations of the upper and lower levels. In Eqs. (1a, b) time is measured in units $\tau_R=\hbar c/(2\pi\omega_0 p^2 n)$ where ω_0 is the transition frequency, p is the induced dipole moment, n is the surface dipole density, and $\mathscr{E}=pE_{ex}\tau_R/\hbar$ is the dimensionless amplitude of the external field. In our system of units the transmitted field is $\mathscr{E}+v$, while the reflected wave is v.

In [1] damping effects have been ignored, *i.e.* the characteristic time T_2 of the relaxation of polarization has been assumed to be much longer then the unit of time

$$T_2=\tau_R/\gamma_{\perp}\gg\tau_R. \tag{2}$$

This relation, however, is not valid generally for materials used in coherent optical experiments, because either the transition dipole moment is small or the concentration of the active atoms is not large enough. Nevertheless, in solids with high dipole density and with allowed dipole transition $\tau_R<T_2$ can be achieved.

In [1] we have shown, that in the absence of damping a pulse-like excitation of the form

$$\mathscr{E}=\mathscr{E}_0\,\mathrm{sech}\frac{t}{\tau} \tag{3}$$

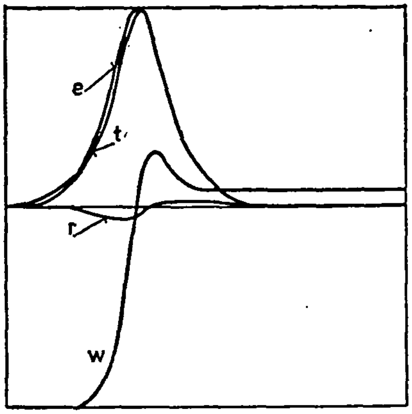

Fig. 1. $A=2\pi$, $\tau=0.25$, $\gamma_\perp=1$

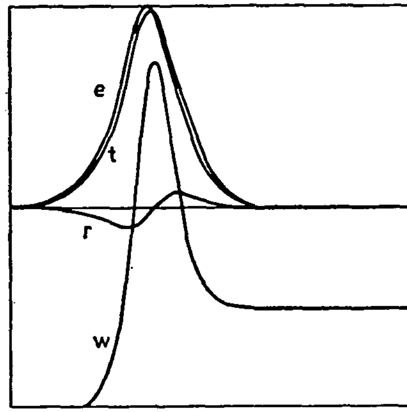

Fig. 2. $A=2\pi$, $\tau=0.25$, $\gamma_\perp=5$

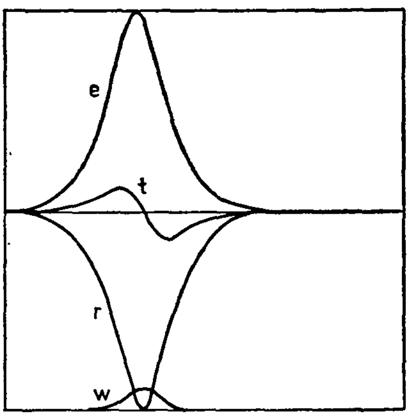

Fig. 3. $A=2\pi$, $\tau=4$, $\gamma_\perp=0$

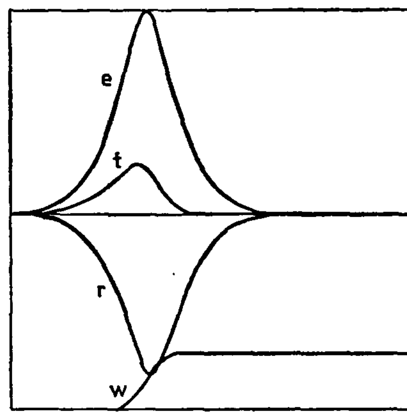

Fig. 4. $A=2\pi$, $\tau=4$, $\gamma_\perp=0.2$

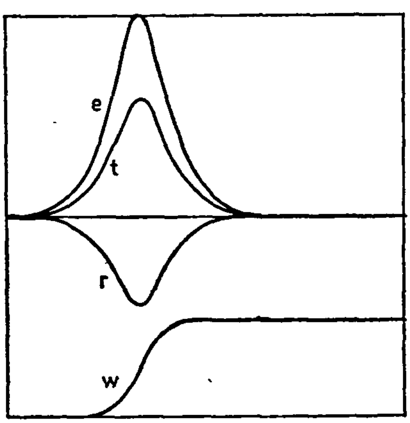

Fig. 5. $A=2\pi$, $\tau=4$, $\gamma_\perp=1$

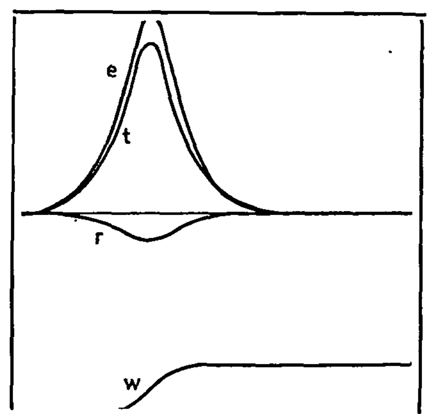

Fig. 6. $A=2\pi$, $\tau=4$, $\gamma_\perp=5$

yields very different behaviour for the transmitted and reflected amplitudes in the cases of $A<(\tau+1)\pi$ and $A>(\tau+1)\pi$, where τ is the duration τ_i of the pulse in τ_R units, *i.e.* $\tau=\tau_i/\tau_R$, and A is the pulse area: $A=\mathscr{E}_0\tau$. In the first case, $A<(\tau+1)\pi$, a complete inversion cannot be achieved and reflexion dominates, while in the second case w reaches $+1$, and then the system goes back to its ground state.

Let us turn our attention to the solution of Eqs. (1a, b). If we have a pulse-like excitation, the stationary values for v is 0 and for w is -1, but as we choose further $\gamma_{\|}=0$, $w=-1$ is not achieved actually, while $v=0$ will be essentially when $\mathscr{E}$ turns to 0. Results of numerical integration are presented in Figs. 1—9, where the time dependence of the inversion (w) and of the exciting (e), transmitted (t) and reflected (r) waves are shown. The scales are fixed by the maximum of the exciting pulse $\mathscr{E}=\mathscr{E}_0 \operatorname{sech} t/\tau$ switched on at $t=-5.5$. Namely its maximum position is at $t=0$, while for the inversion along the vertical scale goes from -1 to 1.

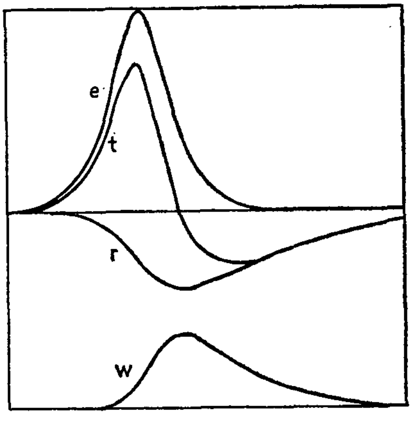

Fig 7. $A=\pi/2$, $\tau=0.25$, $\gamma_{\perp}=0$

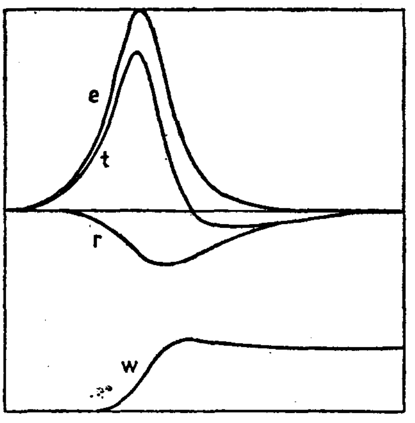

Fig. 8. $A=\pi/2$, $\tau=0.25$, $\gamma_{\perp}=1$

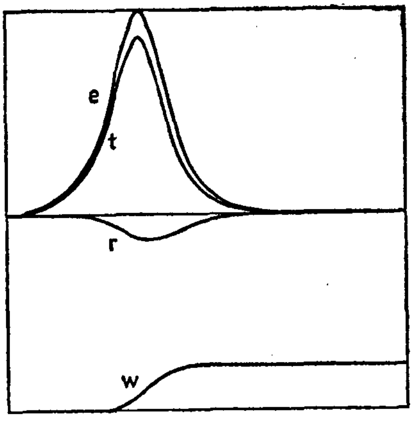

Fig. 9. $A=\pi/2$, $\tau=0.25$, $\gamma_{\perp}=5$

When the reflected wave is small still in the undamped case, *e.g.* for $A=2\pi$, $\tau=0.25$, the introduction of damping will cause a little effect, as demonstrated in Figs. 1 and 2 for $\gamma_\perp=1$ and $\gamma_\perp=5$, respectively. The reflected and transmitted waves are essentially the same as without damping, the only difference is that the inversion does not reach $+1$ and later does not fall back to -1; the atomic system dissipates the energy of the excitation. Damping of the tail of the reflected wave can be observed when $1/\gamma_\perp \sim \tau$. For still greater $\gamma_\perp$ the reflected wave will completely vanish.

The introduction of damping may change the situation radically only if v is relatively large in the undamped case, which is valid for long and/or weak pulses [1]. The situation is shown in Figs. 3—6 for a 2π pulse of duration $\tau_i=4\tau_R$, with $\gamma_\perp=0, 0.2, 1., 5.$, respectively. As $\gamma_\perp$ grows the reflected wave diminishes and transmission is getting closer to the exciting pulse. The same can be observed for a $\pi/2$ pulse with $\tau_i=0.25\tau_R$ (Figs. 7—9) though here the effect is not so drastic, but at $\gamma_\perp=5$ the picture is very similar to the previous case (*cp*. Figs. 6 and 9).

As it is expected, for pulses of duration much less then τ_R the relaxation with characteristic time $T_2 \lesssim \tau_R$ will effect mainly the tails of the transmitted and reflected waves — the superradiant part; the initial stimulated part will be changed only when $T_2 < \tau_i$. In experiments it is easy to meet the condition $\tau_i > T_2 > \tau_R$ and to realize a small area exciting pulse, when a relatively strong reflexion can be expected. However, the more interesting case of strong reflexion of large area pulses requires the condition $T_2 > \tau_i > \tau_R$ which seems more difficult to ensure experimentally.

References

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О ВЗАИМОДЕЙСТВИИ УЛЬТРАКОРОТКОГО СВЕТОВОГО ИМПУЛЬСА С ТОНКИМ РЕЗОНАНСНЫМ СЛОЕМ

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Оптически тонкая двухуровневая атомная система взаимодействует с импульсом резонансного электромагнитного поля. Исследуется влияние релаксации на пропущенную и отраженную волны. Как правило, затухание поляризации уменьшает отражение и усиляет пропускание.