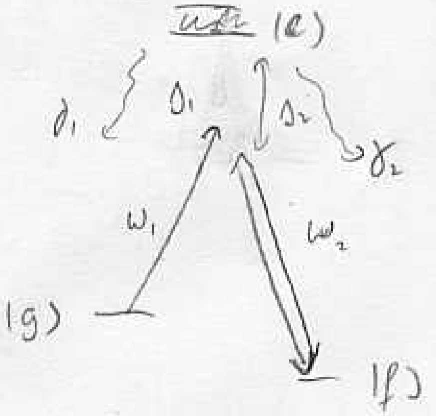
Lecture XXV

Two-photon absorption, Fano profiles

Let us assume large one-photon detuning, $\Delta \gg \Gamma$



$\delta = \Delta_1 - \Delta_2$

weak probe ω_1 and strong control field ω_2

In this limit analytic expressions for the absorption cross section for beam ω_1 and the refractive index seen by beam ω_1 exist, e.g.

Miller et al., PRA 56, 2385 (19..)

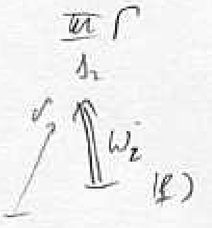
refractive index $\quad n(\delta) = 1 + \frac{3}{8\pi}\tilde{n}\lambda^3 f(\delta)$ $\quad$. $\tilde{n}$ atomic density

$f(\delta) = \frac{\Gamma}{2}\delta \frac{A}{A^2+B^2}$ $\quad$, $A = \omega_2^2 - \delta\Delta_2$, $B = \delta\Gamma$

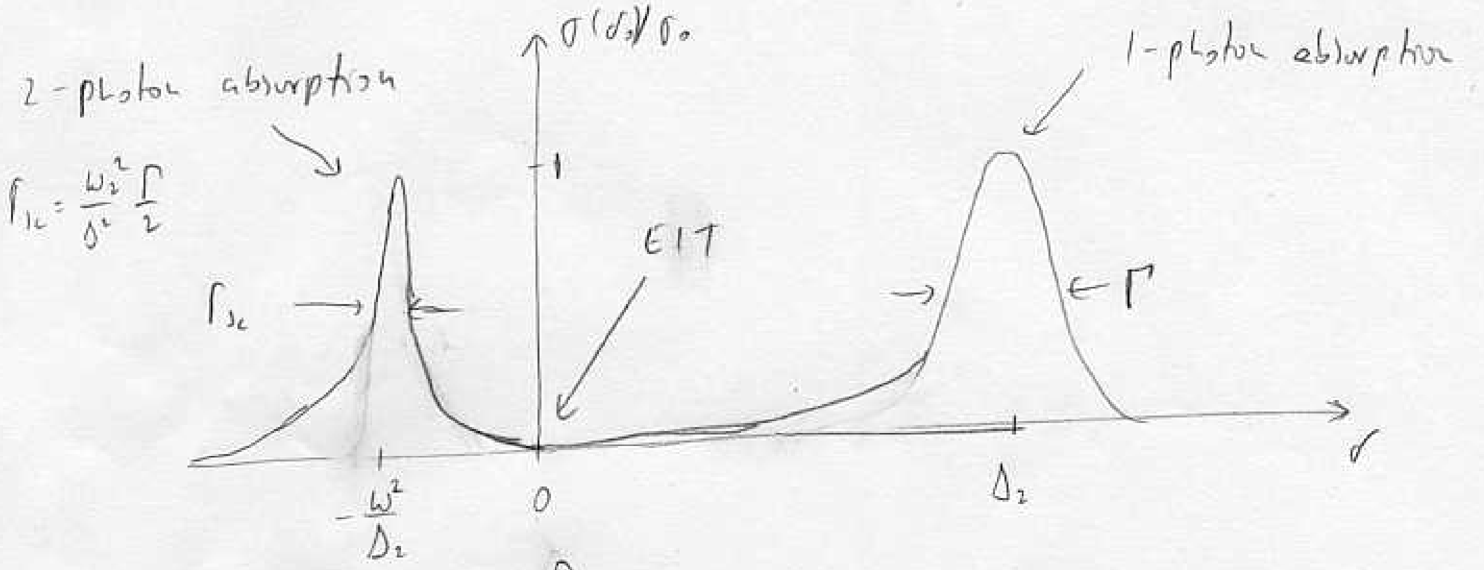
for zero ground-state linewidth

$\sigma(\delta) = \sigma_0\, g(\delta)$ $\qquad \sigma_0 = \frac{3}{2\pi}\lambda^2$,

$$g(\Delta) = \frac{\gamma_2}{2} \frac{dB}{A^2 + B^2}$$



The absorption cross section is for $\Delta_2 > 0$



Probe beam resonant with light-shifted level $|f\rangle$

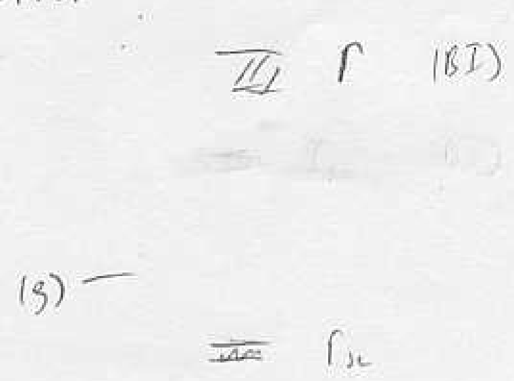
probe beam resonant with unshifted state

Fano profiles:

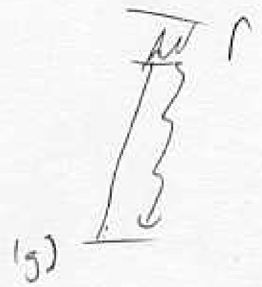
U. Fano
Nuovo Cimento 12, 156 (1935).

API – p. 50

This is like a ground state coupling to one narrow and one wide excited state, except that there is EIT in between because both states decay to the same continuum



$\delta = \Delta_2$

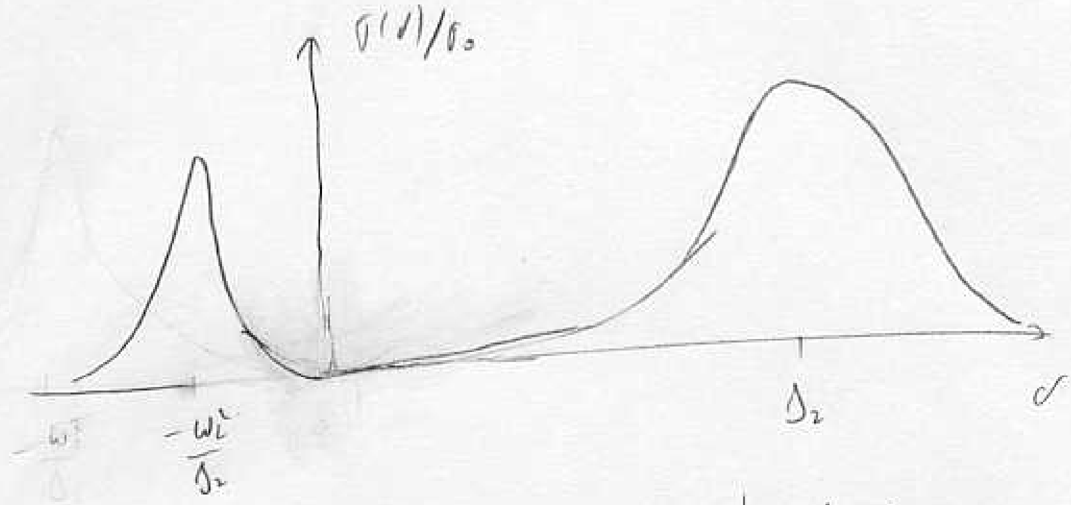


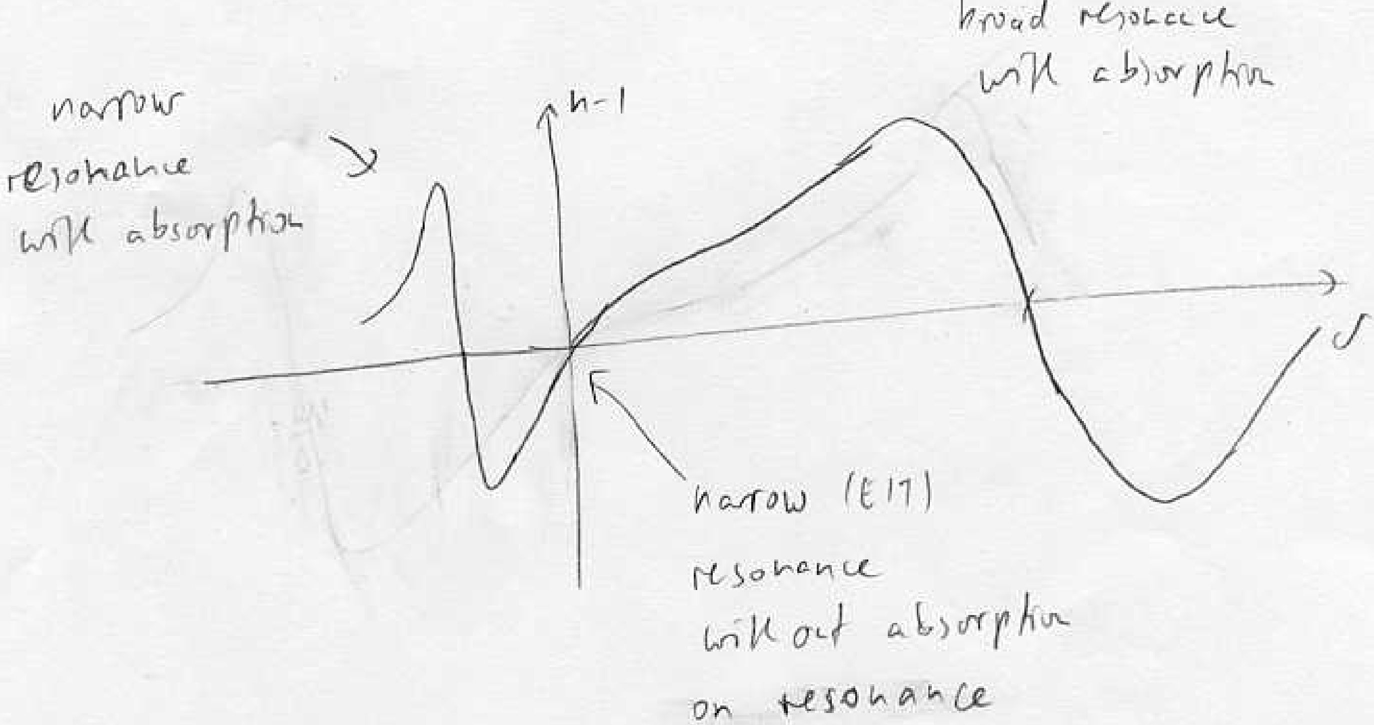
one-photon absorption is two-photon scattering process

$\delta = -\frac{\Omega_2^2}{\Delta_2}$

all orders of Ω_2

two-photon absorption is (at least) four-photon scattering process





For the EIT condition $\nu = 0$, there is no coupling to the excited state, and the refractive index is zero.

In the vicinity of EIT, there is steep dispersion, resulting in a strong alteration of the group velocity of light → slowing and stopping light.

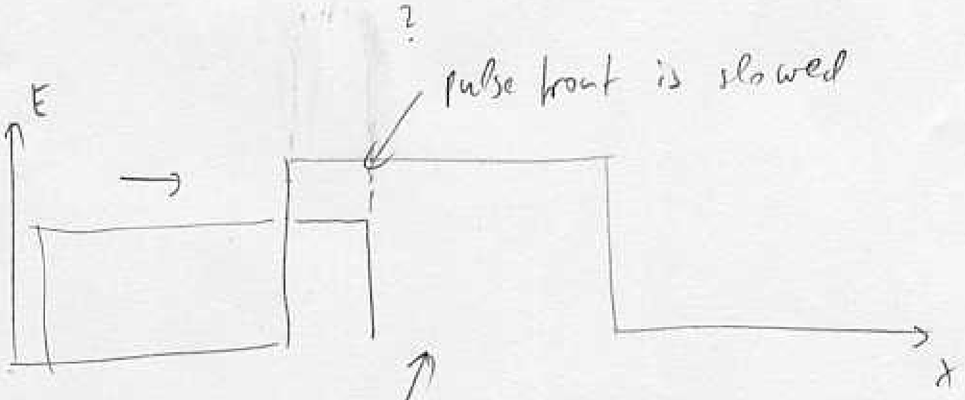
Slow light, adiabatic changes of velocity of light

The group velocity of light in the presence of linear dispersion $\frac{dn}{d\omega}$ is given by

(Harris and Han, PRL 82, 4611 (1999))

$$V_g = \frac{c}{1 + \omega \frac{\partial n}{\partial \omega}}$$ for light of frequency ω

A strong linear dispersion with positive slope near EIT then corresponds to very slow light



$n = 1$

$\frac{dn}{d\omega} = 0$

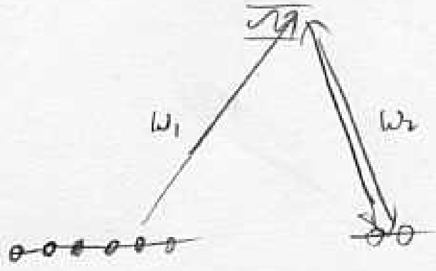
medium with $\omega \frac{\partial n}{\partial \omega} \gg 1$

but $n = 1$

$n = 1 \rightarrow$ electric field unchanged $\rightarrow$ power per area

$\frac{P}{A} = \frac{1}{2} \varepsilon_0 c |E|^2$ unchanged

Pulse is compressed in medium → energy density is increased, light is partly in the form of an atomic excitation : polariton



For sufficiently small ω_2, velocity of light may be very small ... [L.V. Hau, S.E. Harris, Z. Dutton, and C.H. Behroozi, Nature 397, 594 (1999)], as observed in a BEC. What happens if experiment performed in room temperature vapor when $v_{light} < v_{atom}$? The same if setup is Doppler free (copropagating probe and control fields ω_1 and ω_2).

If we change control field adiabatically while the pulse is inside the medium, we can coherently stop light, i.e. convert it into an atomic excitation or spin wave. With the reverse process we can then convert the stored spin-wave back into the original light field. The adiabatic conversion is made possible by the finite splitting between bright and dark states. In principle, all coherence properties and other (qm) features of the light are maintained, and it is possible to store non-classical states of light by mapping photon properties one-to-one onto quantized spin waves.

More about these quanta called "dark-state polaritons" once we have introduced Dicke states.

Is it possible to make use of EIT for, e.g. atom detection without absorption?

Answer: no improvement for such linear processes.

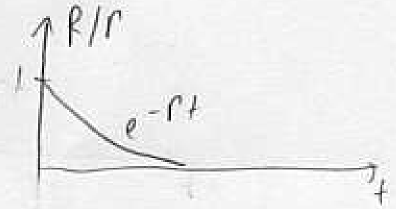
However: improvement for non-linear processes is possible.

Superradiance

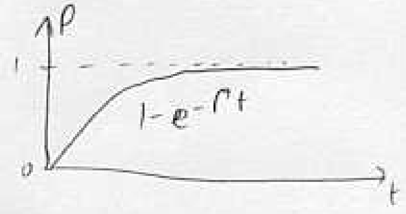
Assume that two identical atoms, one in its ground, and the other in its excited state, are placed within a distance $d \ll \lambda_{eg}$ of each other. What happens?

For a single atom we have for the emission rate $R(t)$ at time t and emission probability $p(t) = \int_0^t R(t')\,dt'$ to have emitted a photon by time t:

$$R_1(t) = \Gamma e^{-\Gamma t}$$

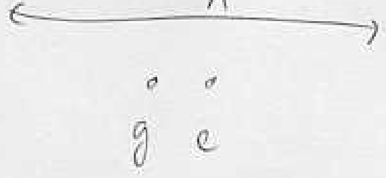


$$p_1(t) = \int_0^t dt' R(t') = 1 - e^{-\Gamma t}$$



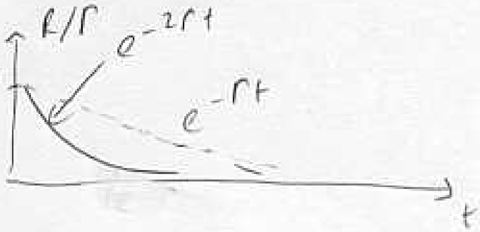
for a single atom.

What about two atoms?

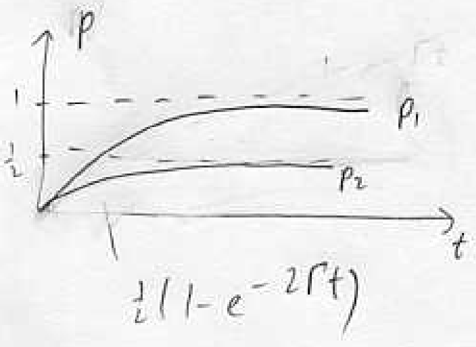


It turns out that the correct answer is

$$R_2(t) = \Gamma e^{-2\Gamma t}$$



$$p_2(t) = \int_0^t R_2(t')\,dt' = \frac{1}{2}\left(1 - e^{-2\Gamma t}\right)$$



The photon is emitted with the same initial rate, but has only probability $\frac{1}{2}$ of being emitted at all!

How can we understand this?

The interaction Hamiltonian is

$$V = -\vec{d}_1 \cdot \vec{E}(\vec{r}_1,t) - \vec{d}_2 \cdot \vec{E}(\vec{r}_1,t) = -\vec{D}\cdot\vec{E}(\vec{r}_1,t) \quad \text{class.}$$

$$V = \hbar g\,(\sigma_1^+ + \sigma_1^-)(a + a^+) \quad g\,(\sigma_2^+ + \sigma_2^-)(a + a^+) \quad \text{QED}$$

$$= \hbar g\,(\sigma_1^+ + \sigma_2^+ + \sigma_1^- + \sigma_2^-)(a + a^+)$$

$$= \hbar g\,(\Sigma^+ + \Sigma^-)(a + a^+)$$

with $\Sigma^\pm = \sum_{i=1}^{2} \sigma_i^\pm$, $\vec{D} = \sum_{i=1}^{2} \vec{d}_i$