Exam Nonlinear Optics

Friday, April 8, 2005, 14.00-17.00 (room 5118.-152)

Give your name on each sheet.
On the first sheet, also give your student number
and the total number of sheets turned in.
Success!

Problem 1 (6 points)

Consider a material consisting of one-dimensional classical anharmonic oscillators with a quadratic force term $-max^2$ as nonlinearity. The density of oscillators is denoted N. Assume that a c.w. light beam is incident: $\tilde{E} = E\exp[-i\omega t] + c.c.$

Derive the susceptibilities: $\chi^{(1)}(\omega)$, $\chi^{(2)}(2\omega)$, and $\chi^{(3)}(3\omega)$. Explain the quantities you introduce.

Problem 2 (6 points)

Consider a sum-frequency generation process.

a) If both fundamental (incoming) pulses are assumed undepleted, how does the signal intensity then depend on the length L of the sample? (Calculation is not necessary.)

b) An important factor in this dependence is the wavevector mismatch. How is this quantity defined? Explain physically why it determines the signal intensity?

c) Now assume that one of the fundamental pulses is depleted, while the other is not. Draw the intensity of all pulses as a function of propagation distance in the sample for zero wavevector mismatch. How would your drawing change if we increase $\chi^{(2)}$ by a factor of 3?

d) How does your first drawing in c) change if the wavevector mismatch is nonzero?

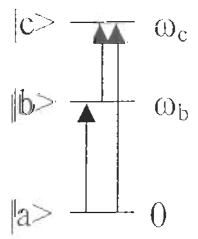
Problem 3 (6 points)

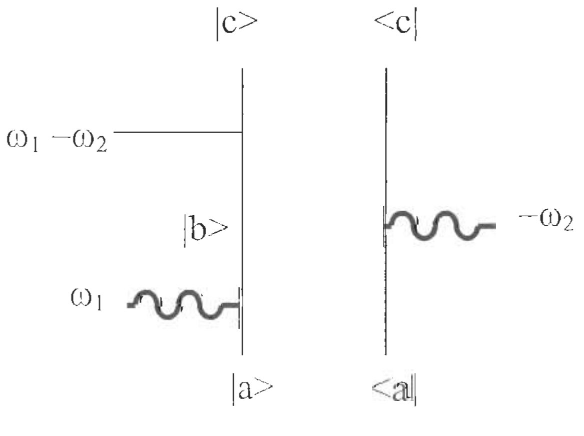
Consider the molecular energy level diagram below, with three levels of interest. The dephasing rate of the coherence |a><b| is given by γ_{ab}, and analogous for the other coherences. The transitions indicated by arrows have a nonzero transition dipole.

a) Calculate the second-order diagram drawn next to the level picture, where two (real) c.w. fields are incident on the system, with $\omega_1 > \omega_2 > 0$.

b) What type of nonlinear optical process does this diagram contribute to? What resonances can occur in this diagram?

c) Is the arrangement of transition dipoles that we assumed possible for a centrosymmetric molecule? Explain your answer.

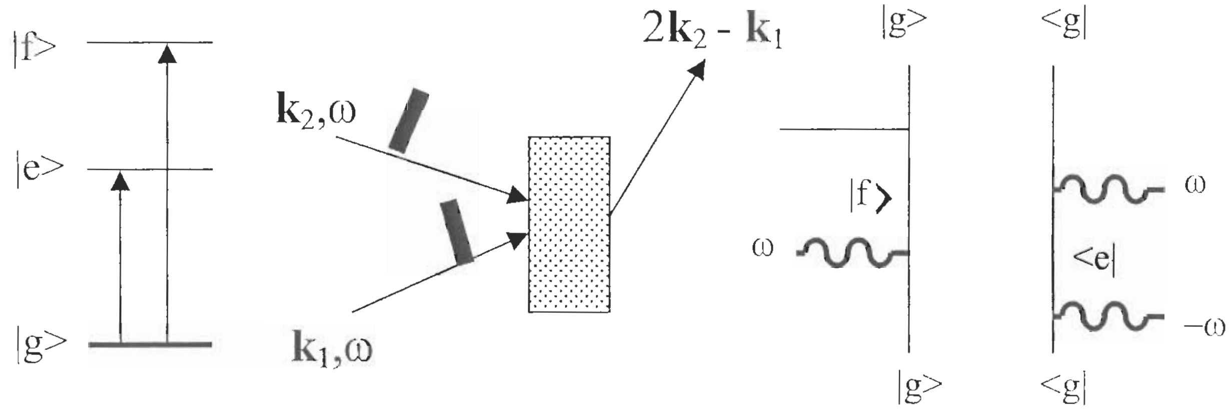




Problem 4 (8 points)

Consider a medium consisting of molecules that may be considered three-level systems. The molecular states are |g> (ground state), |e> (first excited state), and |f> (second excited state). Transition dipoles exist between |g> and |e>, and between |g> and |f>. None of the levels has a permanent dipole.

As a result of inhomogeneities in the system, the molecules do not have exactly the same transition energies. Let us denote the frequencies of the three states by $\omega_g=0$, $\omega_e = \overline{\omega}_e + \delta_e$, and $\omega_f = \overline{\omega}_f + \delta_f$. Here, $\overline{\omega}_e$ and $\overline{\omega}_f$ are the average frequencies, and δ_e and δ_f denote the random inhomogeneous deviations, that vary from molecule to molecule.



Consider a two-pulse photon echo experiment done on an ensemble of these molecules (set-up and parameters as used in the lectures; observation of the signal in the direction $2\mathbf{k}_2$-$\mathbf{k}_1$). Assume that initially all molecules are in the ground state. Consider the contribution to the signal given by the Feynman diagram to the right.

a) Can the diagram be resonant in all interactions?

b) Irrespective of the resonance nature, does the diagram give rise to an echo signal, assuming that δ_f and δ_e are completely uncorrelated for each molecule? **Note**: you do not need to give a complete calculation, a clear motivation of your answer, addressing the relevant phase factors, suffices. If an echo occurs, then give the time at which it occurs and how the echo intensity depends on the various homogeneous dephasing rates in the molecule.

c) Same questions if $\delta_f = k\delta_e$ with k a constant that is the same for each molecule.

Problem 5 (4 points)

a) What is power broadening? What is saturation? (No formulas needed.)

b) Give the physical explanation for both phenomena.