1. Thermal $n_2^{\text{eff}}$

(a) Calculate the nonlocal $n_2^{\text{eff}}$ (defined as $\langle \Delta n \rangle / I_0$) due to laser heating of a liquid characterized by its absorption coefficient $\alpha$ (cm$^{-1}$), density $\rho$ (gr./cm$^3$), heat capacity $C_v$(J/K/gr.) and thermo-optic coefficient $dn/dT$ (K$^{-1}$). The laser intensity is $I(t)=I_0 f(t/\tau_p)$ where $I_0$ is the peak intensity and $f(t/\tau_p)$ denotes the normalized temporal profile of the pulse. Thermal diffusion can be ignored in this problem if we assume that the diffusion time is much longer than $\tau_p$ while being much shorter than the inter-pulse spacing. The latter requirement is for avoiding heat accumulation from pulse to pulse.

(b) Evaluate $n_2^{\text{eff}}$ for liquid CS$_2$ and a pulsed CO$_2$ laser ($\lambda=10.6$ µm) having a square temporal profile ($\tau_p=100$ ns). The CS$_2$ parameters are $\alpha=0.2$ cm$^{-1}$, $\rho C_v=1.3$ J/K/cm$^3$, and $dn/dT=-8 \times 10^{-4}$ K$^{-1}$.

(c) If the sound velocity ($v_s$) in CS$_2$ is $1.5 \times 10^5$ cm/sec., what is the largest laser spot-size ($w_0$) for which the $n_2^{\text{eff}}$ obtained in (b) is valid? What happens as the spot size becomes larger than this value?

2. $n_2^{\text{eff}}$ due to photo-generation of charge-carriers in semiconductors:

(a) Calculate the $n_2^{\text{eff}}$ due to resonant interband charge-carrier generation in semiconductors. The known parameters for the semiconductor are: the band-gap energy $E_g$, the electron effective mass $m^*$ (for both conduction and valence bands), the valence-to-conduction band absorption coefficient $\alpha$, and the carrier recombination time $\tau$. This requires a calculation of the electronic density change $\Delta N$ (in both bands) due to linear absorption followed by the calculation of the resultant index change $\Delta n$ from both bands using a harmonic classical electron oscillator (CEO) model. In this simple approach, the electrons in the valence band are considered bound with a resonant frequency $\omega_0=\omega_0=\omega_{0g}=E_g/\hbar$, while the conduction electrons are considered free ($\omega_0=0$). Ignore damping in the CEO models. The governing equation for $\Delta N$ is:

$$\frac{d\Delta N}{dt} = \frac{\alpha(t)}{\hbar \omega} - \frac{\Delta N}{\tau}$$

where $\hbar \omega$ is the incident photon energy and $I(t)=I_0 f(t/\tau_p)$ is the instantaneous laser intensity. Consider two extreme cases of $\tau_p>>\tau$ and $\tau_p<<\tau$. (You may assume a rectangular pulse).

(b) Evaluate $n_2^{\text{eff}}$ (cm/W) and the effective $\chi^{(3)}$ (esu) for GaAs with $E_g=1.4$ eV, $m^*=0.1 m_0$, $\alpha=100$ cm$^{-1}$, $\tau=1$ ns. The laser wavelength is $\lambda=900$ nm and $\tau_p=10$ ps.

(c) Do you expect an absorptive component $\Delta \alpha$ associated with the above index change $\Delta n$? Explain (briefly).