# NONLINEAR OPTICS (PHYC/ECE 568)

Spring 2022 - Instructor: M. Sheik-Bahae
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## *Homework #1, Due: Thu. Feb. 3*

**Problem 1.** Nonlinear optical measurements show that an optical glass ($SiO_2$) has $\tilde{n}_2=1.3\times10^{-13}$ esu at $\lambda$=850 nm. The linear refractive index $n_0$=1.5

(a) What is $n_2$ in $cm^2/W$ and $m^2/W$? (see Appendix C for unit conversions).
(b) What is $\chi^{(3)}$ in SI units?
(c) Estimate the peak index change ($\Delta n$) induced by a modelocked laser operating at 500 mW (average power), 20 fs laser pulsewith and 100 MHz repletion rate. The laser (Gaussian profile) is focused to a spot size of $w_0$=10 μm.

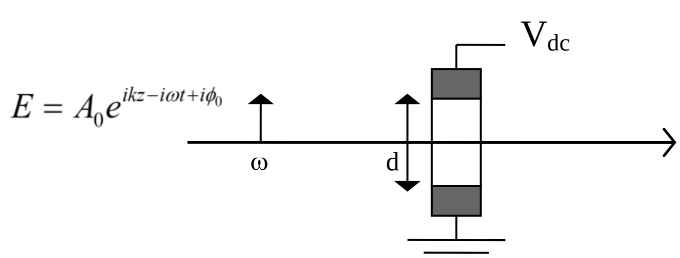
**Problem 2.** Extreme nonlinear optics occurs when the incident optical field approaches the characteristic atomic field $E_{at}=e/(4\pi\varepsilon_0)a_0^2$ where $a_0$ is the Bohr radius (read section 1.1 in Boyd). In this regime, we can no longer describe the nonlinearity by nonlinear susceptibilities as the process becomes non-perturbative. At such high electric fields, the atom simply ionizes.

Calculate $E_{at}$ and its corresponding irradiance $I_{at}$. What is the required pulse energy to achieve this irradiance for a 30 fs laser pulse focused to 20 μm spot size?

**Problem 3. Pockel's Effect:** A 2nd order nonlinear crystal with a known $\chi^{(2)}$, refractive index $n_0$ and a thickness L is used as an electro-optic modulator as shown below. Here a DC voltage ($V_{dc}$) is applied across two transverse electrodes (separated by d).
Ignoring anisotropy and tensor properties, show that the phase of the transmitted electric field will be modulated according to:

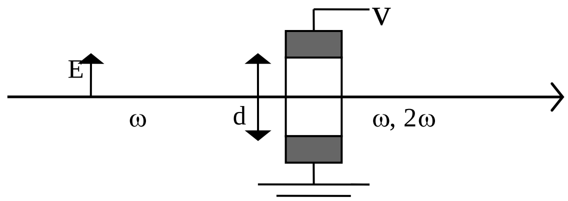
$$\Delta\phi(V) = \kappa V_{dc}$$

(a) What is $\kappa$ (use SI notation)?
(b) For $\chi^{(2)}\approx$1 pm/V, find the required $V_{dc}$ to achieve $\Delta\phi=\pi$ for L=1 cm, $\lambda$=500 nm. Assume d=10 mm, $n_0$=1.5.



**Problem 4. EFISH: Electric-Field Induced Second Harmonic**

Consider a centrosymmetric and isotropic material (e.g. glass) for which $\chi^{(3)}(\omega_4; \omega_3, \omega_2, \omega_1)$ is known. In an experimental arrangement (as shown in the Figure) this material is sandwiched between two parallel electrodes while an intense laser beam is propagating parallel to the electrodes.




**(a)** By applying a large d.c. voltage (V), some second harmonic generation (2ω) is observed. Explain how this is possible. Note (show that) this corresponds to $\chi^{(3)}(2\omega; \omega, \omega, 0)$

**(b)** Assuming $\chi^{(3)} \approx 10^{-22}$ $m^2/V^2$, estimate the required voltage to produce a $\chi^{(2)}_{eff}$ equal to that of KDP ($\chi^{(2)} \approx 1$ pm/V). The electrode spacing d=10 mm.

**(c)** In the small signal regime (i.e. when the incident light intensity is very low), show that the phase of the transmitted beam is modulated by the applied voltage. Explain.