PHGN 480: Laser Physics due 6 Sept 2017
Homework 1 by 5pm

You may use other resources for these (other texts, web), but cite what you use.

1) The following are useful for making estimates – you should memorize these relations:
   a. Wavelength of a photon that has 1eV in energy
   b. Energy (in eV) of a photon with wavelength of 1μm.
   c. Energy (in eV) for kT at room temperature (300K).
   d. Show that for light, $\frac{\Delta\lambda}{\lambda_0} = \frac{\Delta\omega}{\omega_0} = \frac{\Delta\nu}{\nu_0} = \frac{\Delta\sigma}{\sigma_0}$, where the Δ's correspond to bandwidth, and the denominators correspond to the central carrier frequency (or wavelength…). The symbols, in order are: wavelength, angular frequency, frequency, and wavenumber. In these expressions, you can drop any sign you get in the derivation. Hint: write, for example, $\lambda(\omega)$, and use derivatives to show how a variation in ω leads to variation in λ.
   e. These relations are useful to convert spectral bandwidth into different units. As an example, calculate the bandwidth in nm ($\Delta\lambda$) for a signal with $\Delta\nu = 4\times10^{13}\,\text{Hz}$ for the two cases, where the central wavelength is 800nm and 200nm. (Background: the bandwidth required for a laser pulse of a given duration is inversely proportional to $\Delta\nu$, independent of the central frequency or wavelength.)

2) Suppose we have a two-level quantum system, with an energy difference ΔE separating the levels. The two levels have the same degeneracy. Fill in the following table for the thermal equilibrium population ratio N_2/N_1 for the following combinations of temperatures *T* and energy differences ΔE.

	T = 100K	T = 300K	T = 1000K
ΔE = 0.0001 eV			
ΔE = 0.05 eV			
ΔE = 3 eV			

The lowest energy difference is characteristic of rotational transitions in molecules, the next corresponds to molecular vibrational transitions, and the highest energy difference is of the order of magnitude of electronic transitions in atoms and molecules.

3) For a plane wave of intensity 100 W/m^2 (=10 mW/cm^2),
   a. Calculate the electric field strength and the energy density in SI units, where $I = \varepsilon_0 c\, n \langle |E|^2 \rangle$, where the angular brackets denote a time (cycle average) over the electric field $E_0 \cos\omega t$. Assume the wave is in vacuum (*n*=1).
   b. Calculate the corresponding photon flux for a monochromatic beam with wavelengths 500nm and 100μm.

4) First work through Svelto 2.1 for yourself (solution is in book). Now answer these questions: Suppose the bandwidth of a HeNe laser is $\Delta\nu = 1.5\text{GHz}$.

a. Calculate the bandwidth $\Delta\lambda$ in wavelength space. Use the HeNe wavelength of 632.8nm.
b. Calculate the number of modes in the 1 cm-cubed box in this case.
c. Now suppose the field is confined in a 20 cm linear resonator (1D) instead of in a 3D box. Calculate the number of modes within the 1.5 GHz bandwidth of laser.

5) *Two simple ways to measure laser beam size.* Since a Gaussian beam does not have a well-defined edge, it is hard to know exactly the beam size by looking at it. One way is to calibrate a CCD camera, look at a lineout of the beam, and fit it to a Gaussian. There are two other ways to measure the spot size described below. Keep in mind that both assume the beam has a Gaussian shape, which is not always the case for real beams.
   a. Knife-edge scan. Measure the power transmitted past a knife edge placed on a translation stage. You measure the positions for the knife edge that transmit 10% and 90% of the full power. Find a relation between the difference between these two positions and the $1/e^2$ radius of the Gaussian beam. (This is especially useful for focused beams.)
   b. Iris transmission: you center an iris (an aperture that can be changed in diameter) on a beam, and close the iris until one half of the total power is transmitted. Then you measure the diameter of the iris with calipers. Find the connection between this measured diameter and the $1/e^2$ radius of the beam. (This method is best for larger beams.)