Physics 168; Homework #1 Due Thurs. 8/27

1) How many laser pointers would people on Earth have to aim at the precise center of a (new) moon before we could see the moon glow from Earth? Assume a typical laser pointer is 2mW diffraction-limited beam with a 1.0mm output diameter and a wavelength of 650nm. The moon is 380,000 km from Earth, and has a radius of 1740km. Note that "Earthshine" (reflected sunlight from the Earth that hits the moon) is just barely visible from Earth and has an intensity of about 0.5 W/m^2 on the moon's surface; the lasers would need to be about this intense to be seen. (Hint: First figure out how much area the laser pointer spot will cover on the moon.)

2) a) The energy density in electromagnetic fields is $u = \frac{\varepsilon_0}{2}E^2 + \frac{1}{2\mu_0}B^2$. Determine the **average** energy density $\langle u \rangle$ of a plane electromagnetic wave that has a peak electric field magnitude of E_0= 1.0 Megavolts/meter. (For plane EM waves, and even highly-focused lasers, $|\mathbf{E}|=c|\mathbf{B}|$.) Don't forget to average over the oscillations.

b) Calculate I, the intensity of the light. (Intensity is Power per area, $\langle u \rangle$ is energy per volume.) You must prove the relationship between I and $\langle u \rangle$; don't just look it up. You'll need to figure out how much energy passes through a given area, per unit time. Hint: start with a volume, use the known velocity of light!

c) Calculate F, the "photon flux", assuming the wavelength λ=500nm. (Number of photons per second per area).

d) Calculate the Brightness B of this laser, assuming all the light is contained within a diffraction-limited spot-size of 100μm (diameter). (Brightness is power per area per steradian angle; see 1.4.4.)

3) a) Two lasers in vacuum have slightly different frequencies (and therefore slightly different wavelengths). The wavelength difference between the two lasers is $d\lambda$, the frequency difference is $d\nu$. Derive a general equation that relates $d\lambda$ to $d\nu$, assuming the average frequency of the two lasers is ν_0 and $d\nu \ll \nu_0$. Hint: It is *not* $d\lambda\, d\nu = c$; after all, this equation fails when $d\lambda = d\nu = 0$.

b) If a pulsed Ti: Sapphire laser has a central wavelength λ=800nm, and a bandwidth $d\lambda$ =40nm, what is the bandwidth $d\nu$ in units of Hz?

c) What is the minimum pulse duration of the laser in part b?

4) Problem 1.3 (If two energy levels are separated by an energy such that the corresponding transition frequency falls in the middle of the visible spectrum, calculate the ratio of the populations of the two energy levels in thermal equilibrium at room temperature.)

5) Suppose you had a population inversion in a substance that did not have any spontaneous emission. Show how you could still create a laser out of that substance (use a diagram and explain all of the parts). The main problem you need to resolve is that there is nothing to "start" the lasing process.