PHYS302 Fall 2023

Homework 11

1. You are imaging fluorescence from quantum dots that emit 550 nm photons. (A quantum dot a microscopic “island” of material that emits light only at certain wavelengths in a way similar to an atom.)
    a. Your objective lens has diameter of 1.00 inch and focal length of 5.00 cm. How far must two quantum dots be for you to be able to distinguish between them?
    b. Suppose you increase the diameter of your lens but keep the focal length at 5.00 cm. How big should the lens be for you to have a resolution of less than 550 nm?
    c. Now, submerge your whole system in oil (index of refraction is ~1.48 for mineral oil). What is the resolution now (using the lens from part b)? Is it better or worse?

2. The beam (632.8 nm) from a He-Ne laser, which is initially 3.0 mm in diameter, shines on a (perpendicular) wall 100 m away. Given that the system is aperture (i.e. diffraction) limited, how large is the circle of light on the wall?

3. Kerr effect
    a. Explain what a “chirped” pulse is. (You can talk about it in time or in space.)
    b. Explain how the Kerr effect chirps a pulse.
    c. Explain how anomalous dispersion ($dn/d\lambda > 1$) will chirp a pulse.
    d. Optical fibers, such as the ones that deliver internet to residences, are designed to have very little nonlinear effects. The nonlinear index of refraction for fused silica (that they make fibers from) is roughly $n_2 = 2.19 \cdot 10^{-20}$ m^2/W, and its linear index of refraction is roughly $n = 1.55$.
        i. What intensity of light is needed to increase the index of refraction by 1%?
        ii. If that light is inside a fiber that is 128 microns in diameter, what power is this?

4. A laser using a sapphire crystal doped with titanium ions s a gain medium (a "Ti:sapph" laser) is a good choice for a laser that operates in pulsed mode. A certain Ti:sapph laser has pulses of 100 femtosecond duration with the center wavelength of the pulse being 800 nm. The repetition rate of the pulses is 85 MHz. The average power of the laser is 0.5 W.
    a. How much energy is in one laser pulse?
    b. What is the peak power of the laser?
    c. Estimate the spectral bandwidth of the laser, given its pulse duration. (Give the answer in a range of wavelengths: "XX nm - YY nm".)
    d. The laser beam is 2 mm in diameter. If you focus the laser to a single spot using a lens with f = 25 cm, what peak intensity of the laser at the spot where the beam is focused? (You can use the central wavelength to estimate this.)
    e. Now, suppose the lens in part d has a 1 inch diameter.
        i. Use two lenses to form a beam expander such that your laser now has a diameter of 1 inch—it fills the lens. Explain how to do this, draw a picture, and give the ratio of the focal lengths, f1/f2, of the two lenses you will use.
        ii. What is the peak intensity of the laser at the focus now?
        iii. What is the peak electric field at this spot?
    f. <u>Extra credit (#1)</u>:
        i. Is this intensity larger or smaller than the intensity of light at the Sun's surface? (You can estimate this by knowing the distance from the Earth to the Sun, the radius of the sun, and that there is about 1.4 kW per square meter of sunlight on Earth's atmosphere.)
        ii. Is this electric field enough to ionize the air?

5. Explain how light from the sun (blackbody radiation) is different from laser radiation.

   (For example: what sets the "central" wavelength—the color with the most power—in each case; what causes the spectral width/distribution of the light in either case; what is the coherence; etc.)

Extra credit (#2):

In this class, we have been using laser power to estimate some "flow rate" of photons per second. While this is more or less okay to do, it is not valid to say that, for some given average photons in a laser beam, you can expect to only find that number of photons at any time you measure. (This statement is related to photon statistics and the definition of a "coherent state" of light—i.e. the state of laser light.)

Here is an example: you have a box that you are sending a laser into. You have reduced that laser power (through use of "neutral density" filters) to have an average of only 1 photon in the box at any time.

You take a measurement of number of photons in the box.

1. What is the chance you will find 1 photon or fewer?
2. What is the chance you will find 2 photons?
3. What should be the average photon number in the box to ensure that you have less than 1% chance of getting more than 1 photon in the box?

For this problem, use the following equation for P, the probability of finding n photons:

$$P(n, n_{avg}) = \frac{{n_{avg}}^{n}}{n!} e^{-n_{avg}}$$

where n_{avg} is the average number of photons in the box (the expectation value of photon number), and n is the number of photons actually in the box (n refers to a "Fock state" of always exactly n photons—in other words, a state where photon number is an eigenvalue).