Chemistry 620
Analytical Spectroscopy
PROBLEM SET 1: Due 02/21/08

Most of the data required to solve this problem is provided, but a parameter may be omitted as part of the problem. In these cases the student should research the system and insert a reasonable value. Remember, the converse is also true: there is no law that says that every parameter provided is required to answer a question.

1. Even if you've never studied lasers before, you've encountered the theory that explains why a laser system must be based on an active medium that has more than two energy levels. Think about this and explain this fact. Describe the advantages of a four-level laser system over a three-level system,

2. Consider a ruby laser made with a 10 cm long ruby rod and mirrors of reflectivity 0.99 and 0.74. (Ruby is Al_2O_3 doped with Cr.) Assume that the Cr concentration is 1.58×10^{19} cm^{-3} and the transition (absorption/stimulated emission) cross section is 1.27×10^{-20} cm^2 at the lasing wavelength of 694 nm.

   a) Calculate the transmittance of the ruby rod in the absence of the pump.
   b) Calculate the threshold population inversion and the number density of the upper energy level of the lasing transition at the threshold.

3. In a typical He-Ne laser operating at 633 nm the length of the gain medium (cavity) is 0.5 m. The reflectivities of the cavity mirrors are 0.998 and 0.980 for the high reflector and output coupler, respectively. The beam suffers single pass losses totaling of 1.6%. Calculate the *gain threshold*, *threshold population inversion* and *longitudinal mode spacing* in nm for this system assuming the cross-section for stimulated emission is 65e-22 m^2.

4. Calculate the average power produced by a Q-switched Nd:YAG laser pumped to five times its threshold population inversion. You can look for an equation for the pulse energy stored in the cavity, but you can write it yourself if you think about what the population inversion is measuring (here time the units help). The Nd:YAG rod fills the 0.1 m cavity and has a 40 mm^2 cross-sectional area. The cavity mirror reflectivities are 99.99 and 97.5 percent. The beam suffers 2.5% round trip absorption and scattering losses. The repetition rate is 10 Hz. Optical properties of the Nd:YAG active medium are not given, you must find them.

5. One of the reasons that photomultiplier tubes (PMTs) have been such important devices for so long is that they are capable of measuring very low light levels. Consider the PMT response to a single photon. If the anode signal is monitored in 2.5 ns time bins, compute the current that would be observed if the PMT exhibited a gain equal to 10^7 and all the secondary photoelectrons arrived within a single time bin. Compute the voltage this pulse would produce if it were measured across a 50 ohm resistor. Explain the difference between photon counting and

analog signal acquisition for measuring low light signals using PMTs including advice about when each acquisition mode should and should not be used.

6. A photomultiplier tube has a radiant cathodic responsivity of 8.0 mA W^{-1} at 365 nm. It is operated under conditions that produce a gain, m, of 1.5e5 and a collection efficiency, η, of 0.88. If 5.8e-11 A of anodic current can just be detected, what is the minimum detectable flux density in watts and photons per second?

7. The Encyclopedia of Laser Physics and Technology defines the beam divergence as a measure for how fast the beam expands far from the beam waist. This source also points out the $1/e^2$ beam divergence half-angle is $\lambda/(\pi w_0)$, where λ is the wavelength (in the medium) and w_0 the beam radius at the beam waist.
    a. Use this result to find the rough size of the smallest patch of light one can get on the moon when a beam of diameter ~ 10 mm from a Nd:YAG laser is pointed at it in lunar ranging experiments.
    b. Compute the irradiance of the beam on the surface of a 2.5 cm diameter photodiode on the moon's surface.
    c. Compute the current generated in a photodiode that has a responsivity of 0.10 AW^{-1} and efficiency of 0.93.