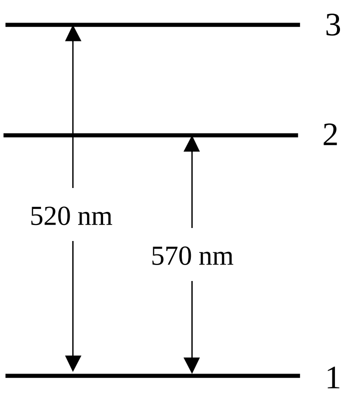
Phys 532 Assignment 6 Due February 27

1. **Optimum Coupling Transmission:** We showed that (in the low-loss limit), the output power of a laser can be expressed as

$$P_{\text{out}} = \pi w^2 I_s T \left(\frac{g_0}{L+T} - 1 \right)$$

where w is the beam width in the medium, I_s is the saturation intensity, g_0 is the small-signal gain, T is the output coupler transmission and L is the additional cavity loss.
(a) In terms of g_0 and L, what value of T provides the greatest output power?
(b) Evaluate P_{out} for this T.

2. **Gain Characterization via Absorption Coefficients:** Suppose a three-level gain medium has the structure shown (assume equal degeneracies). Transitions from level 3 to level 2 proceed via collisions at a rate of 10^{12} s^{-1}. This gives an elastic collision rate of 10^{12} s^{-1} for atoms in level 2 as well, which is the dominant source of line broadening. The density of the medium is $N_a = 10^{17}$ cm^{-3}, and the host index is 1.3. When the medium is in the ground state, the peak absorption coefficients for the $1 \rightarrow 3$ and $1 \rightarrow 2$ transitions are 10 cm^{-1} and 0.1 cm^{-1} respectively.
(a) What is the spontaneous lifetime for the $2 \rightarrow 1$ transition?
(b) A 10-cm long section of this medium is placed in a two-mirror cavity with $T = L = 0.5$, and the pump transition is driven with monochromatic light of intensity I_p. (Assume the pump light enters from the side of the medium, and that the medium is thin enough that reduction in pump intensity due to absorption is negligible.) What is the threshold pump intensity for laser oscillation?
(c) At this pump intensity, what is the saturation intensity for the $2 \leftrightarrow 1$ transition?
(d) If the pump intensity is twice the threshold intensity, and the beam width in the medium is 100 μm, estimate the output power produced.



3. **Number of Longitudinal Modes:** Suppose a gas laser uses Ar^+ ions at a temperature of 2000 K, leading to a Doppler broadened gain profile. The laser wavelength is 514 nm, and it uses a two-mirror resonator of length 0.5 m. The gas density is low, so the index of refraction is 1. Estimate the number of longitudinal modes that will oscillate if the small-signal gain is 1.5 times the total cavity loss coefficient.

4. **Mode Selection:** Suppose it is desired to operate the laser of the previous problem in a single longitudinal mode, by placing an etalon within the cavity. The etalon is a glass plate (index 1.5) of thickness d and with reflective coatings on its faces to give a finesse $\mathcal{F}$. Estimate what values of d and $\mathcal{F}$ are required to yield single-mode output. (You may assume from the outset that the effect of the etalon on the mode spacing of the laser cavity is negligible.) Recall that the transmission through an etalon is

$$T_{\text{etalon}} = \frac{1}{1 + \left(\frac{2\mathcal{F}}{\pi}\right)^2 \sin^2 \frac{\pi\nu}{\nu_F}}$$

(Saleh and Teich, equation 9.1-11). Also, note that it is possible for the finesse to be too high: if the etalon resonance are too narrow, it is unlikely that they will overlap with any laser modes at all.

5. **Gain of a Saturating Amplifier:** Suppose light of intensity $I_{\text{in}} \gg I_{\text{s}}$ is incident on a gain medium having small-signal gain coefficient γ_0 and saturation intensity I_s. Calculate $I(z)$, where z is the distance of propagation through the medium. Is amplification possible in this case?