Coursework 2 - Atom-Photon Physics
Deadline: 7th of December 2012

1. Address the following issues regarding lasers:
   (a) (10/100) What are the pre-requisites for a laser and why?Provide examples
   (b) (10/100) What kind of modes may a laser cavity have?Why?Discuss and explain these modes
2. (15/100) Explain how the Doppler effect is removed in two-photon absorption spectroscopy
3. (15/100) Explain hole burning and saturation-absorption spectroscopy. Why is it useful to study transitions masked by the Doppler broadening?
4. **Laser-gain saturation**. Consider a four-level laser system, with levels from 0 to 3 of energies $E_0, E_{1,}E_2$ and E_3 and populations N_0, N_1, N_3 and N_4.Assume that there is decay γ_{20}, γ_{21}, γ_{10}, γ_{31} and γ_{32}, where we are using the notation $\gamma_{\text{initial level}\rightarrow\text{final level}}$.
   Consider also pumping W_p from level 0 to level 3, and a laser transition W_{21} from2 to 1. Neglect thermal coupling between the first excited and the ground state and assume that $N_0 \gg N_3$, so that the number of atoms per second reaching level 2 is given by the effective pumping rate $R_p = \eta_p W_p N_0$, where η_p represents the quantum efficiency for excitation in level 3.
   (a) (10/100) Make a diagram of this four level system and indicate the laser transition
   (b) (25/100) Show that the steady state population difference $\Delta N_{21} = N_2 - N_1$ is given by

$$\Delta N_{21} = \Delta N_0 \frac{1}{1 + W_{12}\tau_{\text{eff}}},$$

   where ΔN_0 is a small-signal unsaturated population inversion given by

$$\Delta N_0 = \frac{\gamma_{10} - \gamma_{21}}{\gamma_{10}(\gamma_{21} + \gamma_{20})} R_p$$

   and τ_{eff} is an effective time

$$\frac{1}{\tau_{\text{eff}}} = \frac{\gamma_{10}(\gamma_{21} + \gamma_{20})}{\gamma_{10} + \gamma_{20}}.$$

   Hint: start from the rate equations for the populations of the levels 2 and 1.

(c) (15/100) Consider now the saturation intensity, which is the signal intensity W_{12} necessary to reduce the population inversion to the half of its initial value. Does the saturation intensity depend directly on the pumping intensity?What does it depend on?What does this mean, physically?