EE 429/559 Photonics

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Interactive computer simulation homework II: Lasers

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For the second computer simulation homework, we will continue with the three-level laser simulation part of the **LASER** program [Douglas Brandt, John R. Hiller, and Michael J. Moloney, *Modern Physics Simulations: The Consortium for Upper-level Physics Software*, Wiley, New York, 1995]. In this part of the simulation, you may manipulate the atomic energy level spacings, spontaneous lifetimes of the transitions (Einstein A coefficients), temperature, pump power, and output coupler transmission to study the characteristics of laser operation. There are two types of screens: populations and flow rates. The first type shows the populations of each energy level, intensity internal to the cavity (coherent intensity), and the output beam intensity in bar graph form. Qualitative changes in populations and internal intensity due to changes in operating parameters are emphasized in this display. Numerical values of populations are also shown. (An arbitrary value of $N = 400$ total atoms was chosen, partly to avoid the use of scientific notation.)

The second screen type shows the flow rate (atoms/s) between each pair of energy levels. Spontaneous emission, stimulated emission, and absorption are shown, in the form of bars with arrows (the width of the bar being proportional to the flow rate).

Pumping in this simulation occurs between levels 0 and 2, and lasing is possible between levels 2 and 1, or levels 1 and 0. The first case is roughly equivalent to a four-level scheme where pumping is done from level 0 to level 3 which rapidly decays to level 2. The effect of the pump power P is to enhance ϱ_{20} (the blackbody radiation spectral energy density at the frequency that corresponds to the energy level difference $E_2 - E_0$) by a factor of P.

1. **Lack of Lasing With Two Levels**
   Use the program to observe that a two-level system cannot lase. You need to observe that the population of level 1 never exceeds that of level 0 for any choice of parameters for the two-level scheme (**2 levels: no Lasing** under the **Lasers** menu). Record and turn in a summary of all parameters (including temperature, pump power, Einstein A_{10} coefficient) in the two-level scheme for four different sets of conditions.

2. **Einstein A_{mn} Coefficients as Reciprocal Lifetimes**

   (a) Bring up the simulation with lasing between levels 2 and 1 (by selecting **3 levels: Lasing 2 $\longrightarrow$ 1**). Increase the pump power (note that it's the log of the pump power, so the pump power is rising a lot faster than it looks) until the populations of levels 2 and 1 visibly increase. Write down your prediction for what should happen when the A_{21} coefficient is decreased. Keep in mind that this is responsible for spontaneous decays from level 2 to level 1.

   (b) Now decrease the A_{21} coefficient. (The log of A_{21} is represented, and decreasing A_{21} means that the log should become more negative than it was.) Describe what happens to the populations of levels 2 and 1. Explain why you think this is happening. (If this agrees with your reasoning in part (a), you won't have much to add to what was said in part (a).)

   (c) Now slowly decrease the temperature and describe what happens to the populations of levels 1 and 2. Show that this behavior is predicted by the Boltzmann distribution, by writing down and interpreting the equations.

3. **Lasing Threshold, Including Temperature Effects**
   The threshold population difference N_t in the absence of output coupling is taken to be 5% of the total number of atoms present.

   (a) Set A_{21} smaller than others, and set T = 350 K. Increase the pump power until a coherent intensity "bar" shows up on the screen. Increase the pump power. Describe what happens to n_1 and n_2 (the populations of levels 1 and 2) as the pump power is increased. Now decrease the pump power so that it's slightly below threshold. Go to **Do Plot** and select the plot of **Populations vs. Pump Rate**. This plot goes from the present pump power to ten times this value. You should be able to see the kink in the curves that indicates the lasing threshold. This kink is due to the clamping of the population difference at the value N_t.

   (b) Vary the temperature and determine the impact of temperature on lasing threshold pump power. Can you make coherent intensity start or stop at a given pump power by adjusting the temperature? Write down an explanation of how temperature changes should affect the lasing threshold pump power.

4. **Cavity "leakage" to Produce an Output Beam**

   (a) Predict what will happen to the internal intensity W and to the output beam as the mirror transmission T is increased from zero. (The output beam is proportional to both T and W, and is taken to be just $T \times W$.)

   (b) Set conditions for coherent intensity in the cavity. Then gradually increase the mirror transmission and observe the effects on n_2, n_1, W, and the output beam. Carefully describe what happens to n_1, n_2, and W as the mirror transmission T is increased.

Without changing any settings, leave this area and do a plot of **Populations vs. Mirror Transmission**, and then a plot of **Output Intensity vs. Mirror Transmission**. Write down the parameters with no mirror transmission, and explain why the population difference and coherent intensity respond in this manner.

5. **Population Decrease in 1 → 0 Lasing**

   (a) Carry out the $1 \rightarrow 0$ lasing simulation (by selecting **3 levels: Lasing 1 → 0**) and discover how populations n_1 and n_0 behave with increasing pump power beyond lasing threshold. Describe what behavior you found. Do a plot of **Populations vs. Pump Power** beyond lasing threshold.

   (b) Explain in qualitative terms why this behavior is different than is seen in $2 \rightarrow 1$ lasing.

6. **Effect of A_{21} on Coherent Output**
   On a **Flow Rates** screen, X_{mn} is the rate of stimulated emission and absorption between the relevant energy levels, denoted by W_i in your textbook.

   (a) Use a **Flow Rates** screen for $2 \rightarrow 1$ lasing. Set log A_{21} to about -7.5 and mirror transmission to about 0.01. Go above the lasing threshold. Now move A_{21} lower and observe the populations and flow rates. Record your observations.

   (b) Without changing any parameters, go to the other $2 \rightarrow 1$ lasing screen, where populations and coherent intensities are shown. Vary log A_{21} from -7.0 to -10.0 and observe the changes in populations and intensities. Record your observations.