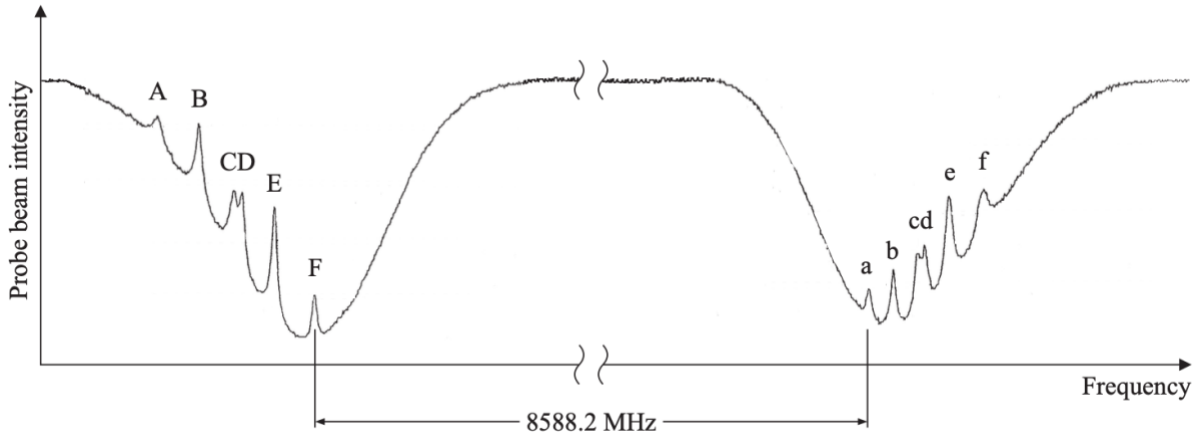
EMA 601/NE 602
Problem set #4
Due 12/15 at 11:59 pm on Canvas, in pdf format

Guidelines:

- Typed solutions are preferred, but you may scan your handwritten solutions as long as the writing is legible.
- Please compile your responses into a single pdf document.
- You are welcome to work together on the problems, but you must write your own responses and code.
- Please show your derivations or describe how you arrived at your responses.

1. (10 points) **Optical pumping** Atoms with $J = 1$ ground states are being excited to J' with a resonant and linearly polarized (π) light. Here, you can assume that the transitions are closed, meaning that atoms that have been excited can only decay back to the ground states.
   (a) (2 points) Identify all allowed transitions $J \rightarrow J'$.
   (b) (6 points) Draw the energy diagrams that include the magnetic sublevels (m_J) for every allowed transition $J \rightarrow J'$. Indicate on each diagram all absorption and spontaneous emission pathways, as well as the sublevel(s) that atoms will accumulate in due to optical pumping.
   (c) (2 points) Evaluate for every allowed transition $J \rightarrow J'$ whether the optical pumping would increase or decrease absorption through the atoms.

2. (20 points) **Laser spectroscopy of caesium (Cs)** Cs-133 has a nuclear spin of $I = 7/2$. Saturated absorption spectroscopy of the $6^2S_{1/2}$ to $6^2P_{3/2}$ transition of Cs-133 vapor yielded the following spectrum. The relative positions of the saturation absorption peaks within each Doppler-broadened dip are also given below in MHz. For this problem, it may be useful to consult the Cs reference data posted under the "Handouts" page on Canvas.



A	0	a	0
B	100.7	b	75.8
C	201.5	c	151.5
D	226.5	d	176.5
E	327.2	e	252.2
F	452.9	f	353.0

(a) (5 points) Draw the energy diagram of the $6^2S_{1/2}$ to $6^2P_{3/2}$ transition of Cs-133, showing labeled hyperfine sub-levels and the allowed transitions between these sub-levels.
(b) (5 points) Assign each peak in the saturated absorption spectrum to the appropriate transition or crossover resonance.
(c) (5 points) Based on the hyperfine energy shift (derived in Lecture 13), justify the following interval rule for the hyperfine splittings: $\Delta E(F \to F+1) = A_{n,l,j}F$. Estimate $A_{n,l,j}$ for $6^2S_{1/2}$ and $6^2P_{3/2}$ based on the relative peak positions.
(d) (5 points) Estimate the temperature of the Cs vapor.