EMA601: Quantum Engineering with Atoms and Photons

University of Wisconsin - Madison
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Practice Set 4

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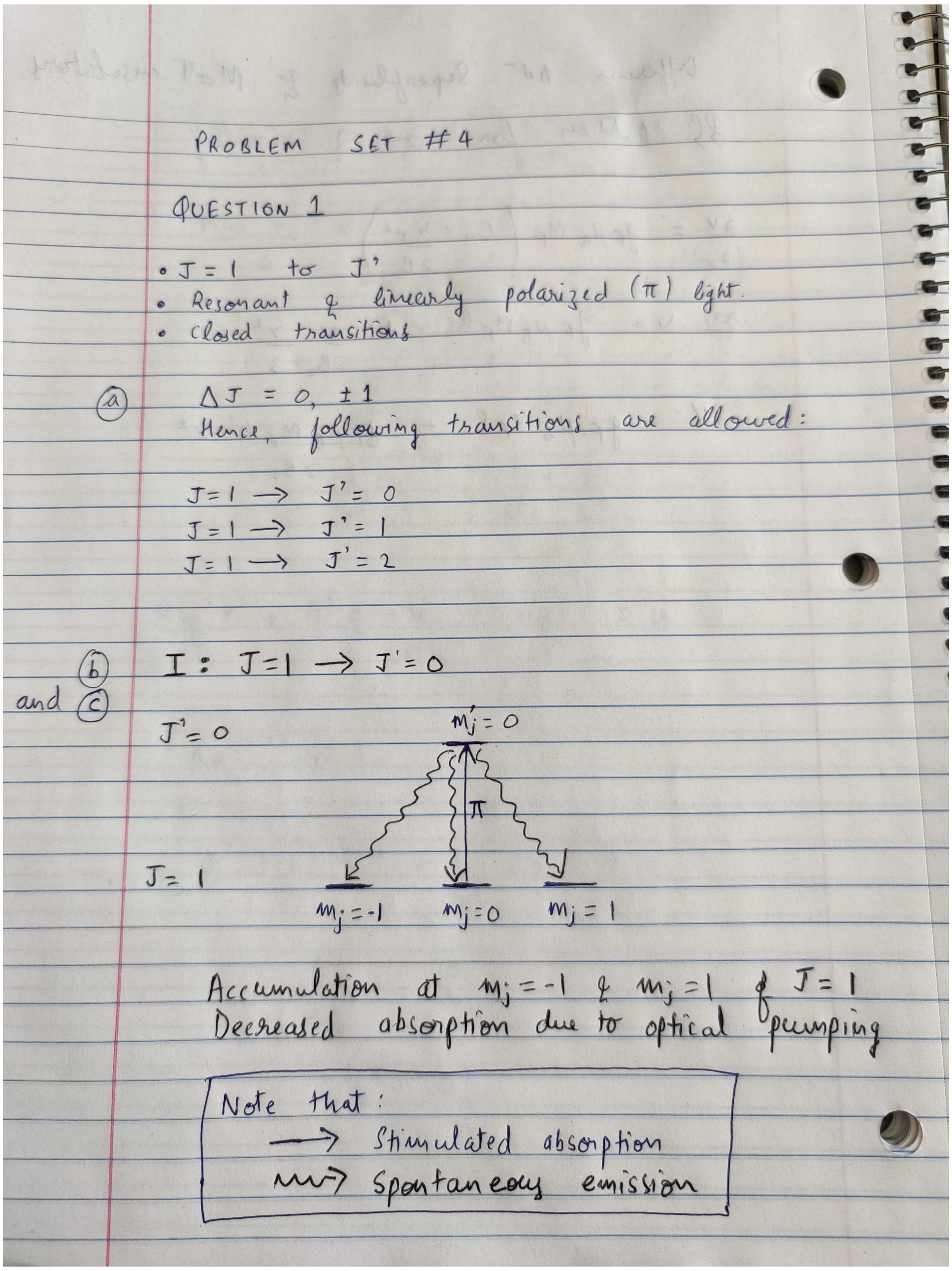
Problem 1: Optical Pumping



PROBLEM SET #4

QUESTION 1

- $J = 1$ to J'
- Resonant & linearly polarized (π) light.
- Closed transitions

(a) $\Delta J = 0, \pm 1$

Hence, following transitions are allowed:

$J = 1 \rightarrow J' = 0$
$J = 1 \rightarrow J' = 1$
$J = 1 \rightarrow J' = 2$

(b) and (c) I : $J = 1 \rightarrow J' = 0$

Accumulation at $m_j = -1$ & $m_j = 1$ of $J = 1$
Decreased absorption due to optical pumping

Note that:
$\longrightarrow$ Stimulated absorption
$\rightsquigarrow$ Spontaneous emission

Figure 1: (a) (b) (c)

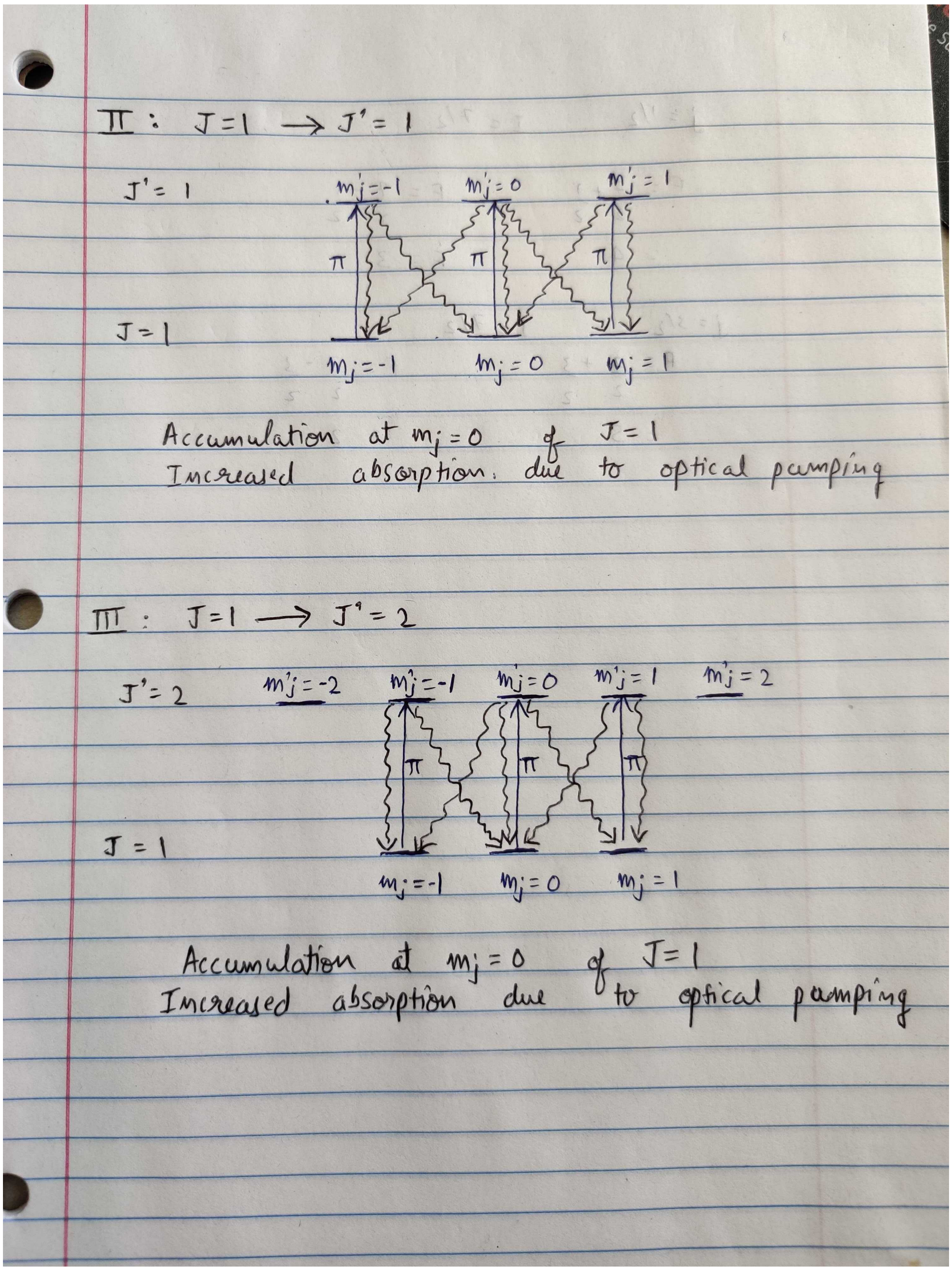


Figure 2: (b) (c) contd...

Problem 2: Laser Spectroscopy of Cs-133

a. Fig. 3 illustrates the hyperfine levels for the given transition of Cs-133. The red and blue group each refer to a doppler broadened group.

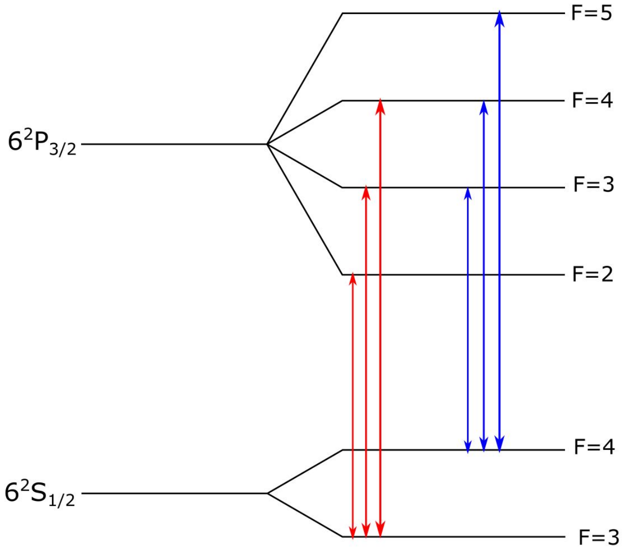


Figure 3: Hyperfine levels and allowed transitions for D-2 line of Cs-133

b. Identifying the peaks

Identifier	Relative Frequency [MHz]	Transition
A	0	$F = 4 \to F' = 3$
B	100.7	crossover $F = 4 \to F' = 3$ & $F = 4 \to F' = 4$
C	201.5	$F = 4 \to F' = 4$
D	226.5	crossover $F = 4 \to F' = 3$ & $F = 4 \to F' = 5$
E	327.2	crossover $F = 4 \to F' = 4$ & $F = 4 \to F' = 5$
F	452.9	$F = 4 \to F' = 5$
a	0	$F = 3 \to F' = 2$
b	75.8	crossover $F = 3 \to F' = 2$ & $F = 3 \to F' = 3$
c	151.5	$F = 3 \to F' = 3$
d	176.5	crossover $F = 3 \to F' = 2$ & $F = 3 \to F' = 4$
e	252.2	crossover $F = 3 \to F' = 3$ & $F = 3 \to F' = 4$
f	353.0	$F = 3 \to F' = 4$

c. The following formula was derived in Lec #13 for hyperfine energy splittings:

$$\Delta E_{HFS} = \frac{A}{2}[F(F+1) - j(j+1) - I(I+1)]$$

and, if we choose F appropriately, we can write:

$$\Delta E(F \to F+1) = \Delta E(F-1 \to F)$$

therefore, we can write:

$$\Delta E(F \to F+1) = \Delta E_{HFS}(F) - \Delta E_{HFS}(F-1)$$

$$\Delta E(F \to F+1) = \frac{A}{2}[F(F+1) - j(j+1) - I(I+1)] - \frac{A}{2}[(F-1)F - j(j+1) - I(I+1)]$$

$$\Delta E(F \to F+1) = A.F$$

Here, $A = A_{n,l,j}$.
In the $6^2S_{1/2}$ state, the transition between F=3 and F=4 is denoted by $\nu_{3,4} = 9.192631770$ GHz. Hence:

$$h\nu_{3,4} = A_{6^2S_{1/2}} \times F$$

$$A_{6^2S_{1/2}} = \frac{h \times 9.192631770\ GHz}{4}$$

$$A_{6^2S_{1/2}} = h\ \times\ 2.2981579425\ GHz$$

In the $6^2P_{3/2}$ state, the transition between F=3 and F=4 is denoted by $\nu_{3,4} = 201.287$ MHz. Hence:

$$h\nu_{3,4} = A_{6^2P_{3/2}} \times F$$

$$A_{6^2P_{3/2}} = \frac{h \times 201.287\ MHz}{4}$$

$$A_{6^2P_{3/2}} = h\ \times\ 50.32175\ MHz$$

d. Using the reference document, we can obtain the value of ω_o; and the $\Delta\omega_D$ for this spectrum is approximated as the $\Delta\nu = A$ to $D\ = 452.9$ MHz. We use these values in the equation derived in Lec # 21, slide 22:

$$T = \frac{\Delta\omega_D^2\, c^2\, m_{atom}}{8\, ln2\, k_B\, \omega_o^2}$$

$$T = 430.3642\ K$$