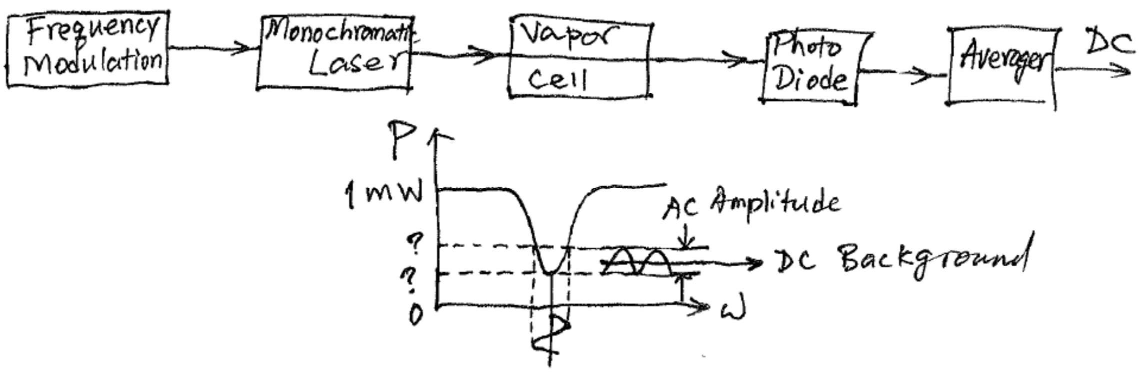
ASEN-6265. Fundamentals of Spectroscopy for Optical Remote Sensing
Homework #11 (Laser Spectroscopy)

1. A monochromatic laser beam with power P = 1 mW is sent through a 1-m long sample cell filled with absorbing molecules. The absorbing transition has the Doppler width $\Delta\omega_D = 2\pi \times 10^9$ Hz and a peak absorption coefficient $\alpha(\omega_0) = 10^{-3}$ cm^{-1}, where ω_0 is the resonance frequency of the molecule. The laser frequency is modulated while it is tuned to the molecular resonance frequency ω_0, i.e., $\omega_L = \omega_0 + \Delta\omega \cos 2\pi ft$, where $\Delta\omega = 2\pi \times 10$ MHz.
(1) Calculate the maximum AC amplitude of the detector output signal for a detector with a sensitivity of 1 V/mW.
(2) How large is the DC background signal if the detector output is averaged over time?



2. A monochromatic laser beam is sent through a sample of diatomic molecules. The laser wavelength is tuned to a vibration-rotation transition $(v'', J'') \rightarrow (v', J')$ with an absorption cross section of $\sigma_{ik} = 10^{-18} cm^2$, where $v_i'' = 0, J_i'' = 20$ and $v' = 1, J' = 20$.
(1) Estimate the fraction n_i/n of molecules in the level ($v_i'' = 0, J_i'' = 20$) at T = 300 K (vibrational constant $\tilde{\nu}_e$ = 200 cm^{-1}, rotational constant B_e = 1.5 cm^{-1}).
(2) Calculate the absorption coefficient for a total gas pressure of 10 mbar.
(3) What is the transmitted laser power P_t behind an absorption path length of 1 m for an incident power P_0 = 100 mW?

3. (1) Summarize how to detect atoms or molecules using spectroscopy methods.
(2) Summarize the approaches of how to improve detection sensitivity.
(3) Choose two of the following spectroscopy methods to describe their principles, experimental setup, required detectors, and applications: photoacoustic spectroscopy, optothermal spectroscopy, ionization spectroscopy, optogalvanic spectroscopy, cavity ring-down spectroscopy, and frequency-modulation spectroscopy.

4. To summarize the approaches for sub-Doppler spectroscopy -- how to achieve high spectral resolution, please briefly describe the principles of how the following methods achieve Doppler-free spectroscopy. You may draw the experimental setup or

spectral figure to help your understanding and explanation.

(1) Saturation absorption spectroscopy,
(2) Polarization spectroscopy,
(3) Multiphoton spectroscopy,
(4) Molecular beam, and
(5) Laser cooling/trapping.

5. (*Optional problem for Doppler-free spectroscopy*)

(1) A collimated sodium beam is crossed by the focused beam (focal area A = 0.2 x 0.01 cm^2) of a single-mode cw dye laser, tuned to hyperfine component (F'=1 → F" = 2) of the D_2 transition $3^2S_{1/2} \rightarrow 3^2P_{3/2}$ of Na. Calculate the saturation intensity I_S if the mean velocity of sodium atoms is v = 5 x 10^4 cm/s. The lifetime τ_K of the upper level is τ_K = 16 ns and the residual Doppler width can be neglected.

(2) How large is I_S in a sodium cell at $P_{Na} = 10^{-6}$ mbar with P_{Ar} = 10 mbar additional argon pressure? The pressure broadening is 25 MHz/mbar for Na-Ar collisions.

HW #11 is due on Thursday, April 20th, 2017 in class.