Estimation of CaH density in cell

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In our experiment, we observed 10% absorption of CaH in a 6K cell. We would like to know what the CaH density is.

$$I = I_0 e^{-n\sigma z}, \tag{1}$$

where I is the intensity of laser passing through the cell, I_0 is the original intensity of laser, n is the CaH density, σ is the absorption cross section, and z is the length of the cell.

Since the interaction length, z, is set by the cell size, we only need to evaluate the absorption cross section, σ, in order to estimate the density.

From eq. (29) in [2], we learn

$$\sigma(\omega) = \frac{1}{4}(g_2/g_1)\lambda^2 g(\omega) A_{21}, \tag{2}$$

where g_1 and g_2 are the degeneracy factors of the two levels, λ is the transition wavelength, $g(\omega)$ is the line shape function, and A_{21} is the Einstein A coefficient.

The nature linewidth of CaH, 2.2 MHz, is much smaller than the doppler linewidth of CaH at 6K, which is 118 MH. We can use doppler line shape for $g(\omega)$ in (2).

$$g(\omega) = \frac{1}{\sqrt{\pi}\Gamma} e^{-\frac{(\omega-\omega_0)^2}{\Gamma^2}}, \tag{3}$$

where Γ is given by

$$\Gamma = \frac{2\pi}{\lambda}\sqrt{\frac{2k_BT}{m_{CaH}}}. \tag{4}$$

Our laser was locked to stabilized He-Ne via a Fabry Perot cavity, so we can assume our laser frequency is half of the nature linewidth away from resonance. Now, let's calculate absorption cross sections first. For $\lambda = 695$ nm, $A_{21} = 14.3 \times 10^6$ (s^{-1}) [1], nature linewidth, γ=$2\pi\times$ 2.3 MHz (note: we use angular frequency here),

$$\begin{aligned}\sigma(\omega = \omega_0 + \gamma/2) &= \frac{1}{4}\lambda^2\frac{1}{\sqrt{\pi}}\frac{\gamma}{\Gamma}e^{-\frac{1}{4}\frac{\gamma^2}{\Gamma^2}} \\ &= 2.2\times 10^{-11}cm^2.\end{aligned} \tag{5}$$

From Eq.(1) and Eq.(5), we can compute the density of CaH.

$$\begin{aligned}\frac{I}{I_0} &= 0.9 = e^{-\sigma(\omega=\omega_0+\gamma/2)nz} \\ \Rightarrow n &= 9.5\times 10^8 \simeq 10^9(1/cm^3),\end{aligned} \tag{6}$$

where we use $z = 5$ cm.

References

[1] M.D. Di Rosa. Laser cooling of molecules. 2004.

[2] R.C. Hilborn. Einstein coefficients, corss sections, f values, dipole moments, and all that.