Phys 4062/5062 – Lecture Five – Heating due to Spontaneous Emission

Outline

1. Recall Cooling Rate

2. Calculate Heating Rate due to Fluctuations

3. Use Photon Absorption Rate – R

4. Find Equilibrium Temperature – Doppler Limit $T_{Doppler}$

5. Explore Estimates for Temperature Limits

Heating

- prediction of $E = E_o \exp[-t/\tau]$, that energy → 0 is unphysical
- so far: we have ignored heating due to fluctuations in force
- both absorption and spontaneous emission involve momentum transfer in unit of ħk

Atom executes random with walk step size ħk due to these processes

- number of steps is proportional to number of photons absorbed/emitted
- absorption equally probable from both beams for v ~ 0 atoms
- absorption + spontaneous emission – 2 steps in random walk one from random absorption and one from random emission

Number of Steps, $dN = 2\, R_{total}\, dt$ **(21)**

$R_{total} = R_+ + R_-$ (Total Absorption Rate) where R is given by (13)

ID Random Walk

Average momentum, $\langle p \rangle = 0$ **(22)**

Mean Square

$\langle p^2 \rangle = N(\hbar k)^2$ **(23)**

Rate of Heating

$$\frac{dE}{dt}_{heat} = \left(\frac{1}{2M}\right)\left(\frac{d\langle p^2\rangle}{dt}\right) \quad \textbf{(24)}$$

Using equations (23), (21), (13), and (24),

$$\frac{dE}{dt}_{heat} = \left[\left(\frac{(\hbar k)^2}{2M}\right)\left(\frac{4\left(\frac{I}{I_S}\right)\Gamma}{1+\frac{4\Delta^2}{\Gamma^2}}\right)\right] \quad \textbf{(25)}$$

To find equilibrium temperature, assume steady state conditions

$$\frac{dE}{dt} = \frac{dE}{dt}_{cool} + \frac{dE}{dt}_{heat} = 0$$

Using equations (18A), (17) and (25)

$$E_{steadystate} = \left[\frac{1+\frac{4\Delta^2}{\Gamma^2}}{2\left(-\frac{\Delta}{\Gamma}\right)}\right]\left[\frac{\hbar\Gamma}{8}\right] = \frac{k_B T}{2} \quad \textbf{(26)}$$

- energy per degree of freedom = $\frac{k_B T}{2}$ according to equipartition theory

Find expression for temperature T

Minimize expression for temperature to find $T_{min} = \hbar\Gamma/2k_B$ at $\Delta = -\Gamma/2$

$$T_{min} = T_{Doppler} \text{ (Doppler Limit)}$$

- estimate $T_{Doppler}$ for Rb
- estimate Doppler FWHM of cold RB

Note: Temperature of molasses of MOT is typically well below $T_{Doppler}$ because of the mechanism of polarization gradient cooling

Explore Estimates for temperature limits

1. Recoil limit T_γ
2. Spectral Limit T*
3. Doppler Limit T_D

Notice $T_D = (T^* T_\gamma)^{1/2}$