

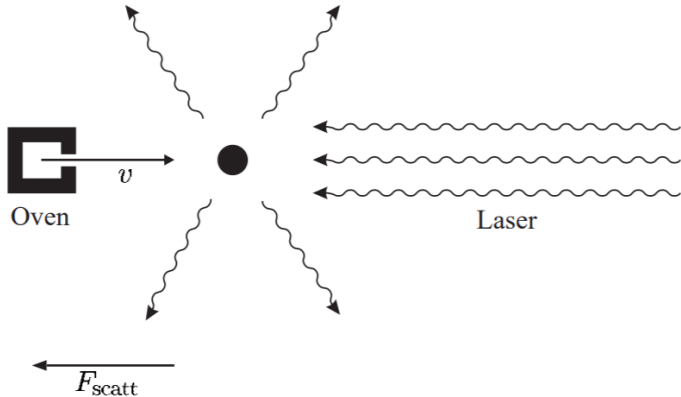
Basics of laser cooling for ions and neutral atoms

Quantum Engineering II

3rd of June 2021

The scattering force

$$\delta = \omega - \omega_0 + kv,$$



The force is given by

$$\mathbf{F} = \frac{d\mathbf{p}}{dt} \\ = \hbar \mathbf{k} \cdot \Gamma_{\text{scat}}$$

where

$$\Gamma_{\text{scat}} = \Gamma \rho_{22} \\ = \frac{\Gamma}{2} \frac{I/I_{\text{sat}}}{1 + I/I_{\text{sat}} + 4\Delta^2/\Gamma^2} \quad (\text{steady state})$$

$$F_{\text{max}} = \hbar k \frac{\Gamma}{2}$$



Slowing an atomic beam

Compensation of Doppler shift by Zeeman effect shall obey:

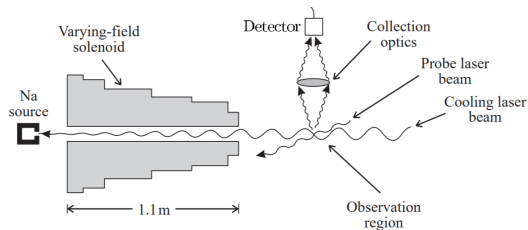
$$\omega_0 + \frac{\mu_B B(z)}{\hbar} = \omega + kv$$

The required magnetic field is then:

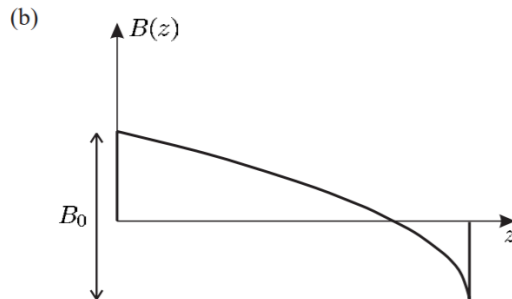
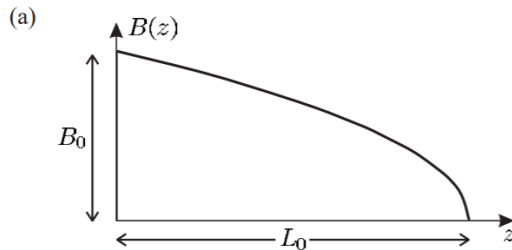
$$B(z) = B_0 \left(1 - \frac{z}{L_0}\right)^{1/2} + B_{bias}$$

where

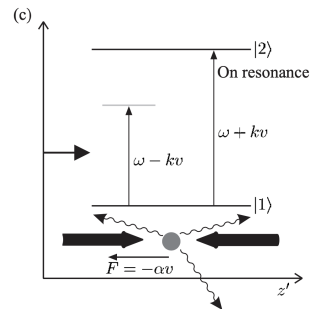
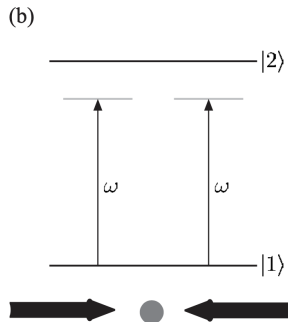
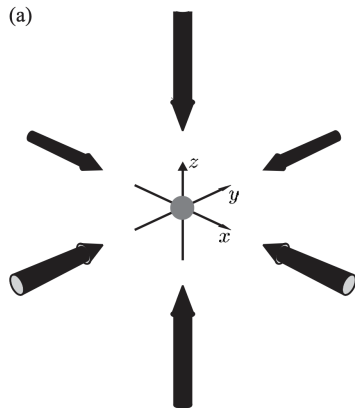
$$B_{bias} = \frac{\hbar}{\mu_0} (\omega - \omega_0)$$



Slowing an atomic beam



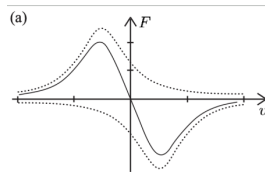
Optical molasses



Optical molasses

$$\begin{aligned}
 F_{\text{molasses}} &= F_{\text{scatt}}(\delta - kv) - F_{\text{scatt}}(\delta + kv) \\
 &= -2 \frac{\partial F}{\partial \omega} kv, \quad kv \ll \Gamma \\
 &= -\alpha v
 \end{aligned}$$

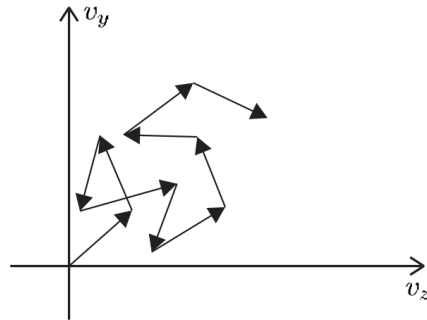
$$\alpha = 2k \frac{\partial F}{\partial \omega} = 4\hbar k^2 \frac{I}{I_{\text{sat}}}$$



Cooling Limit

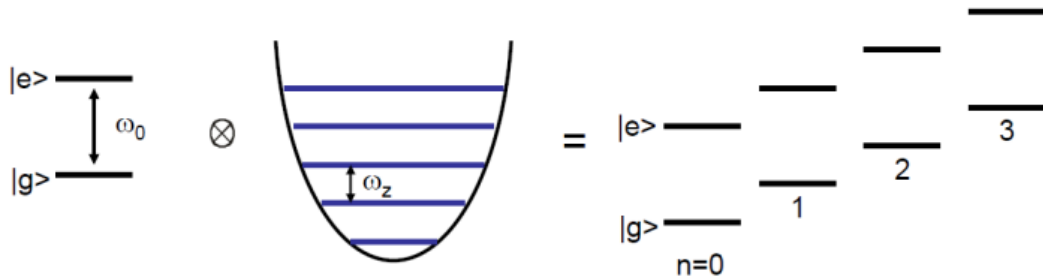
$$\mathbf{F} = \mathbf{F}_{\text{abs}} + \delta\mathbf{F}_{\text{abs}} + \mathbf{F}_{\text{spont}} + \delta\mathbf{F}_{\text{spont}}$$

$$k_B T_D = \frac{\hbar\Gamma}{2}$$



Resolved Sideband Cooling

Laser cooling trapped ions in linear Paul trap. Motion in x, y is quantized like harmonic oscillator



Resolved Sideband Cooling

Jaynes-Cummings model

$$H_{JC} \propto \hat{a}^\dagger \hat{b} + \hat{a} \hat{b}^\dagger$$

Which drives the transitions:

$$|g\rangle|n\rangle \iff |e\rangle|n-1\rangle$$

Spontaneous emission climbs down the later

