Physics 4062/5062 – Lecture Four- Laser Cooling Force and Motional Damping

Outline

Previous Lecture

Classical Damped Driven Harmonic Oscillator

Rate of Photon Absorption

Force due to absorption of light

This Lecture

Effect of Doppler Shift

Net Force for Laser Cooling

Damping Coefficient

Time Constant for Motional Damping

Future Lectures

Heating Rate

Equilibrium Temperature – The Doppler Limit

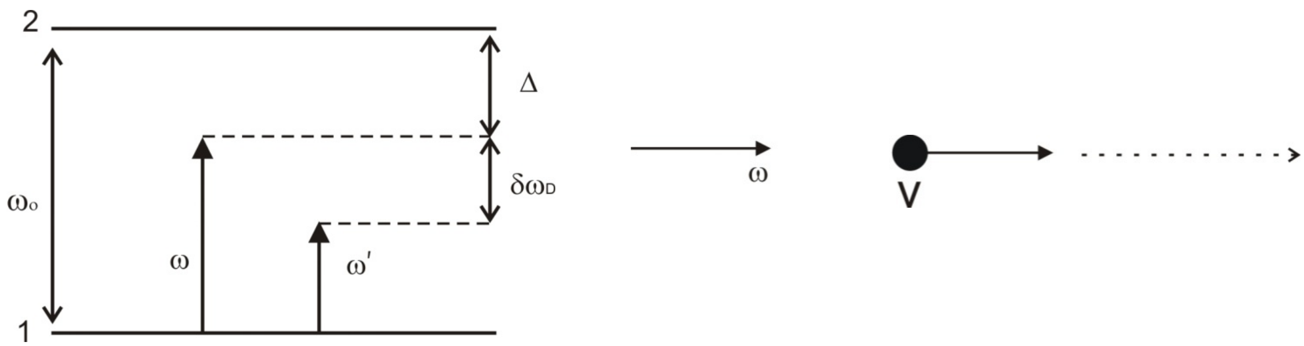
Doppler Cooling – Motional Damping

Recall Force Due to Absorption

$$F_{abs} = \left[\frac{\frac{I}{I_{sat}}}{1+\frac{4\Delta^2}{\Gamma^2}}\right]\hbar k\Gamma \qquad \textbf{(14)}$$

Here, $\Delta = \omega - \omega_o$ which is the detuning in the lab frame

Effect of Doppler Shift



Recall Expression for Doppler Shift

$$\delta\omega_{Doppler} = \omega' - \omega = \pm\left(\frac{v}{c}\right)\omega = \pm kv$$

- ω' – atom frame frequency
- ω – lab frame frequency

For 1D case of Atom moving away from Field

$$\omega' = \omega - kv \Rightarrow \delta\omega_{Doppler} = -kv$$

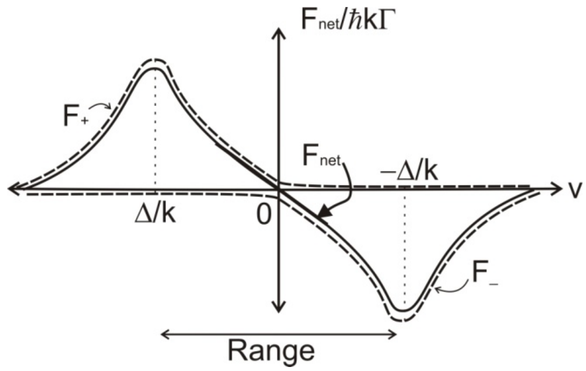
Laser Cooling Configuration [1D = 2 counter propagating lasers]

$$F_+ = \frac{\left(\frac{I}{I_s}\right)\hbar k\Gamma}{1+\frac{4(\Delta-kv)^2}{\Gamma^2}} \qquad F_- = \frac{\left(\frac{I}{I_s}\right)\hbar k\Gamma}{1+\frac{4(\Delta+kv)^2}{\Gamma^2}}$$

Net Force:

$$F_{net} = F_+ + F_- = \left(\frac{I}{I_s}\right)\hbar k\Gamma\left[\left(\frac{1}{1+\frac{4(\Delta-kv)^2}{\Gamma^2}}\right) + \left(\frac{1}{1+\frac{4(\Delta+kv)^2}{\Gamma^2}}\right)\right] \qquad \textbf{(15)}$$

This is a plot using $\Delta = -\Gamma/2$ and $I = I_s/10$



- F_{net} is approximately linear around v =0
- F_{net} is positive for v < 0

- Range ~ 1 m/s for typical atom
- Cooling is effective only for slow atoms

Show that $F_{net} = -\alpha v$ and that the motional damping coefficient α is given by

$$\alpha = 8\left(\frac{I}{I_s}\right)\hbar k^2\left[\frac{2\left(-\frac{\Delta}{\Gamma}\right)}{\left[1+\left(\frac{2\Delta}{\Gamma}\right)^2\right]^2}\right] \qquad \textbf{(17)}$$

Note that α is positive for Δ < 0

Show that kinetic energy damping can be modeled by the equation

$$\frac{dE}{dt} = -\alpha\frac{2E_k}{M} \qquad \textbf{(18A)}$$

Show that the time constant for exponential decay of kinetic energy is given by

$$\tau = \frac{M\left(1+\left(\frac{2\Delta}{\Gamma}\right)^2\right)^2}{16\hbar k^2\left(\frac{I}{I_s}\right)\left(-\frac{2\Delta}{\Gamma}\right)} \qquad \textbf{(20)}$$

- estimate τ for Rb