Physics 4062/5062 – Lecture Two Outline

1. Doppler Width

2. Velocity/Speed Distribution

3. Techniques for Atom Slowing

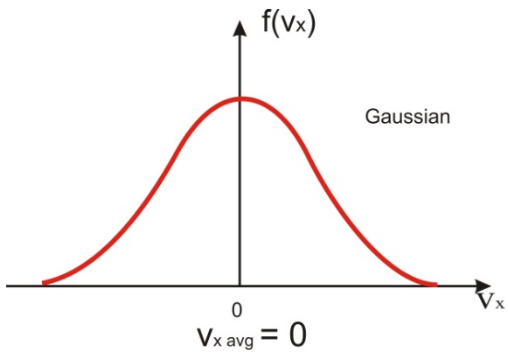
Cooling Atoms from Vapour

Atoms in chamber have Maxwell Boltzmann velocity distribution

Equilibrium distribution characteristic of room temperature

$F(v_x,v_y,v_z) = f(v_x)f(v_y)f(v_z)$

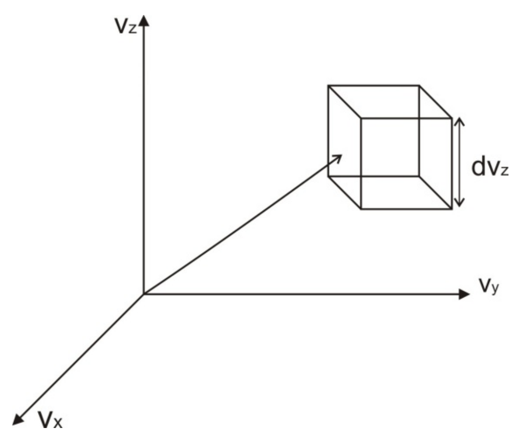
$f(v_x) = (\frac{m}{2\pi k_B T})^{\frac{1}{2}} \exp\left[-\frac{m v_x^2}{2k_B T}\right]$



- For 3D distribution, velocity components only occur as combination
  $v_x^2+v_y^2+v_z^2$

  $(v_x^2)_{avg} = \frac{k_B T}{m}$

Picture of velocity distribution – fraction of velocities with vectors ending in all volume $dv_x\ dv_y\ dv_z$



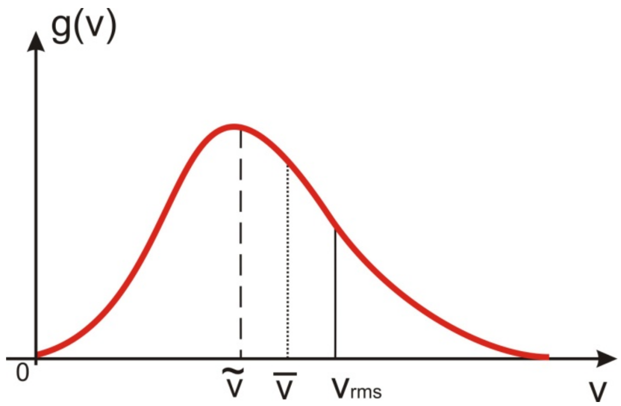
2D Representation

- distribution of points in velocity space
- density depends on "distance v" = $(v_x^2+v_y^2)^{1/2}$
- density maximum at origin

Speed Distribution

Ng(v) dv = number with speed between v and v + dv

where g(v) us the speed distribution given by



$$g(v) = 4\pi\left(\frac{m}{2\pi k_B T}\right)^{\frac{3}{2}} v^2 \exp\left[-\frac{mv^2}{2k_B T}\right]$$

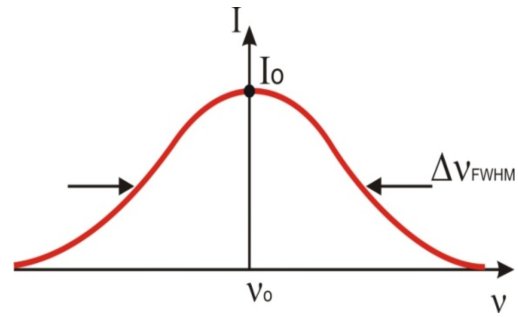
$$\bar{v} = \left(\frac{8k_B T}{\pi m}\right)^{\frac{1}{2}}$$

$$\tilde{v}_{\text{most probable}} = \left(\frac{2k_B T}{m}\right)^{\frac{1}{2}}$$

$$v_{rms} = \left(\frac{3k_B T}{m}\right)^{\frac{1}{2}}$$

Doppler Width

$$n\, f(v_x)dv_x = n\left(\frac{m}{2\pi k_B T}\right)^{1/2} \exp\left[-\frac{m{v_x}^2}{2k_B T}\right] dv_x$$



$n\, f(v_x)dv_x$ is a density – (Atoms/unit volume) with velocity between v and v + dv

$$\text{Recall } \frac{\Delta\nu}{\nu_o} = \pm\frac{v_x}{c}$$

$$\text{so } dv_x = \frac{c}{\nu_o} d\nu$$

$$\frac{dn}{n} = \left(\frac{m}{2\pi k_B T}\right)^{1/2} \exp\left[\frac{-m}{2k_B T}\left(c^2\left(\frac{\Delta\nu}{\nu_o}\right)^2\right)\right]\left(\frac{c}{\nu_o}\right) d\nu$$

Description of Fluorescence Intensity Profile

- fraction emitting/absorbing between ν and dν is given by

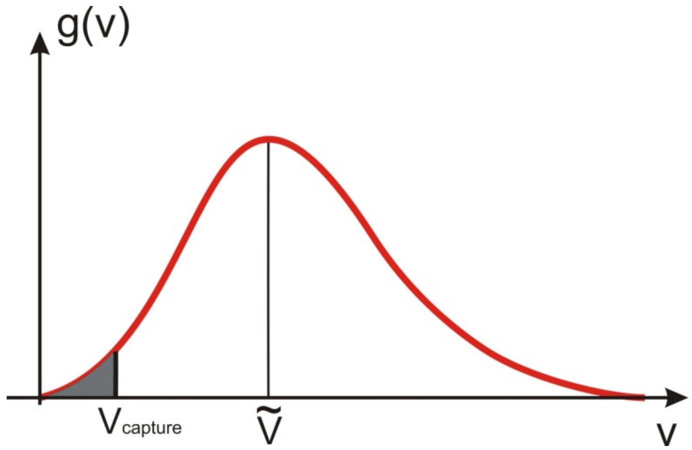
$$I = I_o \exp[(-m/2k_B T)c^2(\Delta\nu/\nu_o)^2]$$

- setting $\frac{I}{Io}$ = ½ and finding the full width half maximum

$$\Delta\nu_{FWHM} = \left(\frac{2\nu_o}{c}\right)\sqrt{\frac{2k_B T \ln 2}{m}} \sim \left(\frac{2}{\lambda}\right)\tilde{v}$$

$$\Delta\nu_{FWHM} \sim k\tilde{v} \text{ where } k = 2\pi/\lambda$$

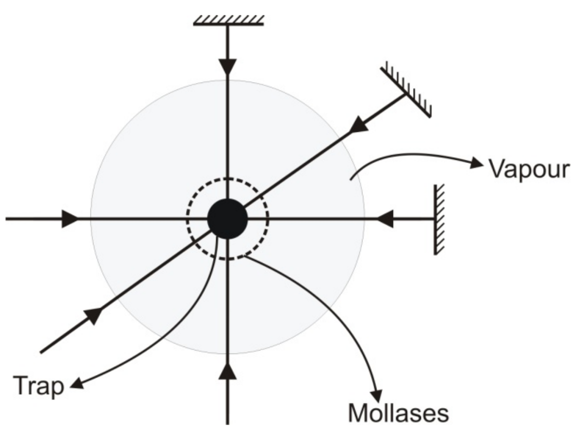
Considerations for Slowing Atoms from Vapour

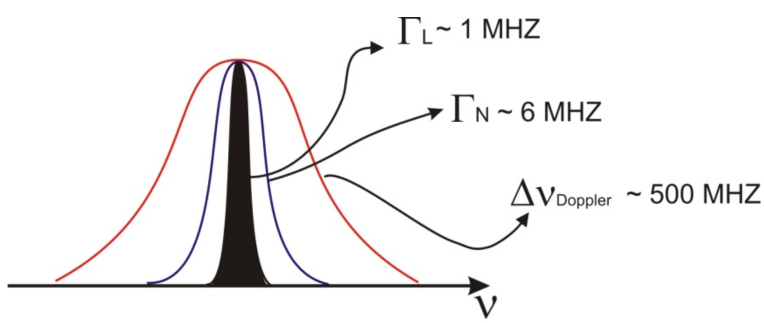


$\tau_{transit} \sim \frac{D}{\tilde{v}} \sim \frac{1 \text{ cm}}{250 \text{ m/s}} \sim 50$ ms

- transit time through beam is $\sim \frac{D}{\tilde{v}}$
- D is beam diameter
- Only atoms in low speed tail slowed sufficiently to be trapped

For MOT/Molasses





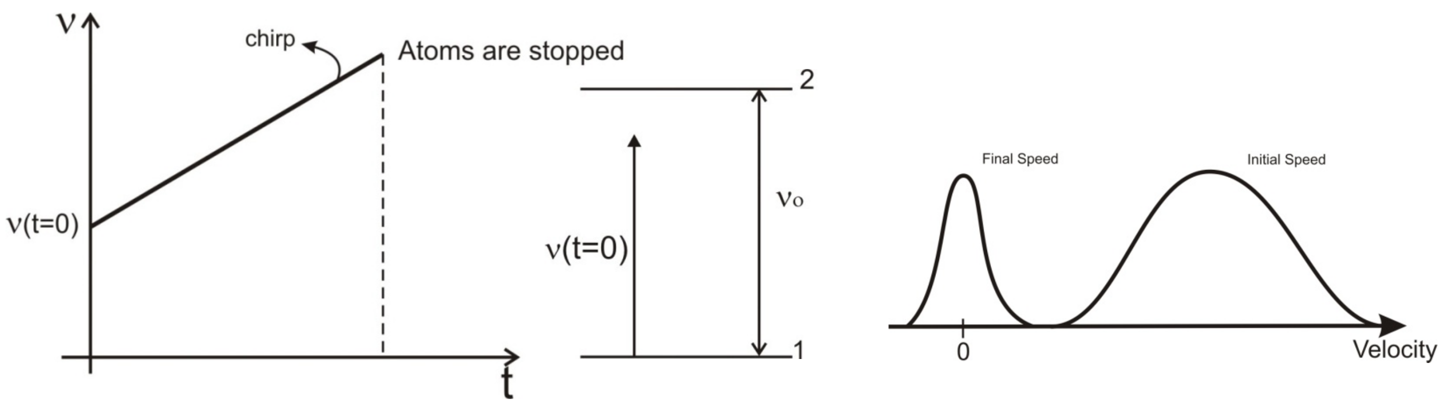
Note: $\Delta\nu_{Doppler}$ for cold atoms $< \Gamma_L$

Techniques for Slowing Atoms

Beam Loaded MOT- atoms slowed from atomic beam are trapped
Vapour Cell Loaded MOT - atoms in tail of speed distribution are slowed and trapped

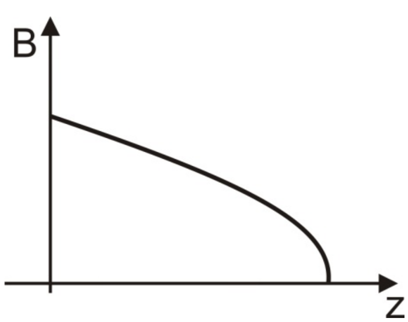
Slowing Atomic Beams

1. Chirp Slowing
    - Typical chirp rate ~ 1 GHz /ms



Atoms absorbing photons will be Doppler shifted
So laser frequency is changed to keep laser on resonance
Tune laser to correspond to most probable velocity from oven

2. Zeeman Slowing



B field from tapered solenoid produces spatially changing
Zeeman Shift that keeps atoms on resonance as it slows down