# Laser cooling and trapping

Mittwoch, 18. Januar 2023 16:07

Zoom lecture tomorrow. Sorry.

Exam Thu Feb. 16 $9^{00}$

Thu Mar. 16 $9^{00}$

---

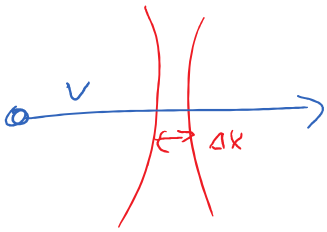
velocity of atoms → Doppler effect

1st order Doppler : $\Delta\omega \propto \frac{v}{c} \cdot \omega \approx \mathcal{O}(10\,\text{GHz})$

2nd order Doppler: $\Delta\omega \propto \left(\frac{v}{c}\right)^2$

atom = clock
laser = clock } relative motion + special relativity

velocity of atoms → finite interaction time laser vs. atoms




$\Gamma_{ttb} \propto \frac{\mathcal{O}(1)}{\tau}$

↑
transit time broadening

$v = \frac{\Delta x}{\tau}$

⇒ need cold ≡ slow atoms, ideally trapped

# COOLING OF GASES BY LASER RADIATION[1*]

T.W. HÄNSCH[2†] and A.L. SCHAWLOW
*Department of Physics, Stanford University, Stanford, California 94305, USA*

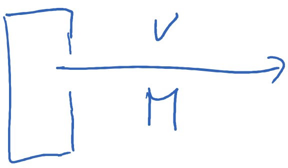
Received 20 October 1974

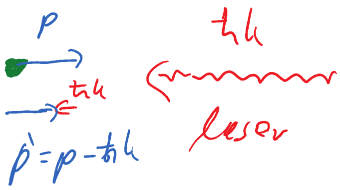
It is shown that a low-density gas can be cooled by illuminating it with intense, quasi-monochromatic light confined to the lower-frequency half of a resonance line's Doppler width. Translational kinetic energy can be transferred from the gas to the scattered light, until the atomic velocity is reduced by the ratio of the Doppler width to the natural line width.

Cooling of this order could be achieved quite quickly. When a photon of momentum $h\nu/c$ is scattered by an atom of mass $M$, moving towards it with a velocity $v$, the average change in velocity is

$$\Delta V = \frac{\Delta(Mv)}{M} - \frac{h\nu}{Mc}.$$

photons have a momentum $p = \frac{h\nu}{c} = \hbar k$

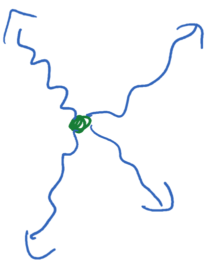



absorption of counterprop. laser photon

$\Rightarrow v' < v$

2. emission



photon momenta average to zero

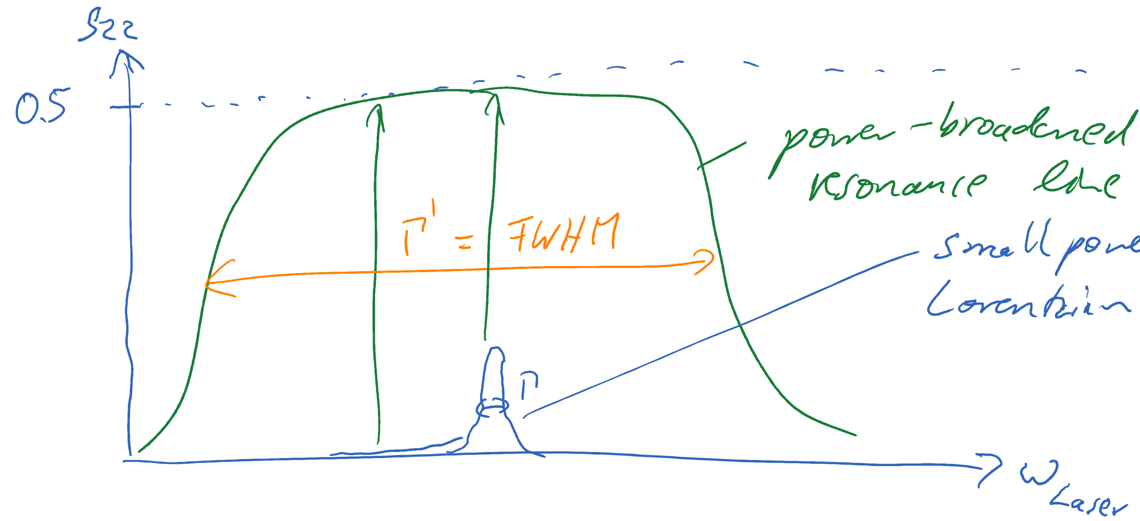
$\longleftarrow$ $F_{scatt}$ scattering force

$$F_{scatt} = \hbar k \cdot \underbrace{\Gamma \cdot \rho_{22}}$$

$F_{scatt} = \hbar k \quad \underbrace{\gamma_{sc}}_{\hookrightarrow \text{ scattering rate}}$

$\downarrow$ photon momentum

strong laser: power broadening




$\Gamma' = \text{FWHM of resonance} = \Gamma \cdot \sqrt{1 + S_0}$

$\hookrightarrow$ saturation parameter

photon scattering rate

$$\gamma_{ph} = \frac{S_0}{1+S_0} \cdot \frac{\Gamma/2}{1 + \frac{4\delta^2}{\Gamma'^2}}$$ power-broadened Lorentzian

$$\gamma_{ph}^{max} = \frac{\Gamma}{2}$$ (high laser power: $\rho_{22}^{max} = 0.5$)

$F = M \cdot a$

$$\Rightarrow a_{max} = \frac{\hbar k \Gamma}{2M} = \frac{v_r}{2\tau}$$

e.g. Na: $\tau = 16\,ns$ $\quad \lambda = 589\,nm$

$M = 23\,u$

$$v_r = 3\,cm/s$$

$$a_{max} = 9 \cdot 10^5 \frac{m}{s^2} = \underline{\underline{10^5 g}}$$

slowing down atoms changes Doppler shift

$\Rightarrow$ atoms go out of resonance

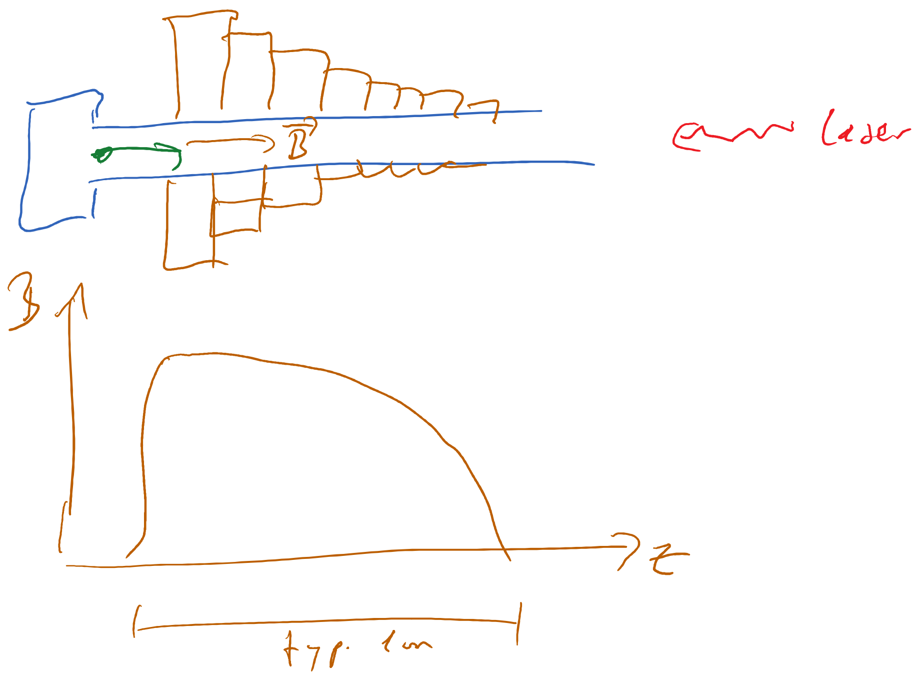
chirp cooling: change laser frequency

$\rightarrow$ Zeeman slower

Bill Philips Nobel 1997

position-dependent magnetic field shifts compensate for

- " - Doppler shift




Design: constant deceleration $a = \eta \cdot a_{max}$ $\eta < 1$

safety margin

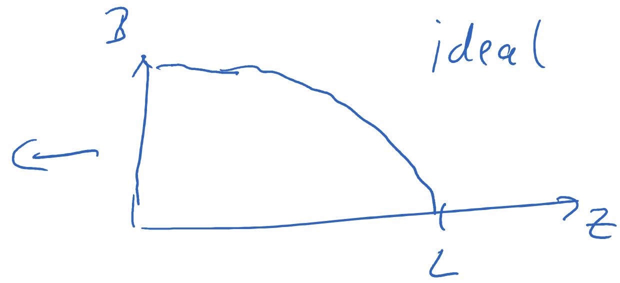
$$\frac{dv}{dt} = v\frac{dv}{dx} = -a$$

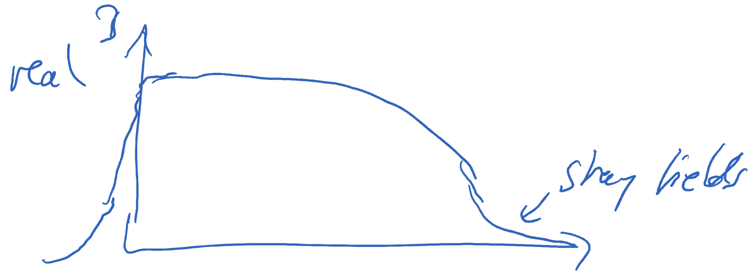
$$v_0^2 - v^2 = 2az$$

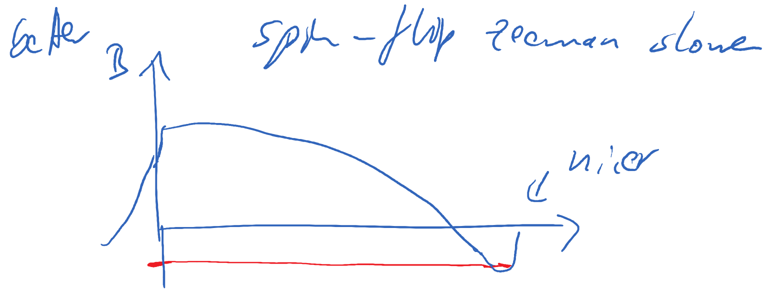
$$L = \frac{v_0^2}{\eta a_{max}}$$

$$B = B_0\sqrt{1-\frac{z}{L}}$$

$$L = \frac{M v_0^2}{\eta \hbar k \Gamma}$$



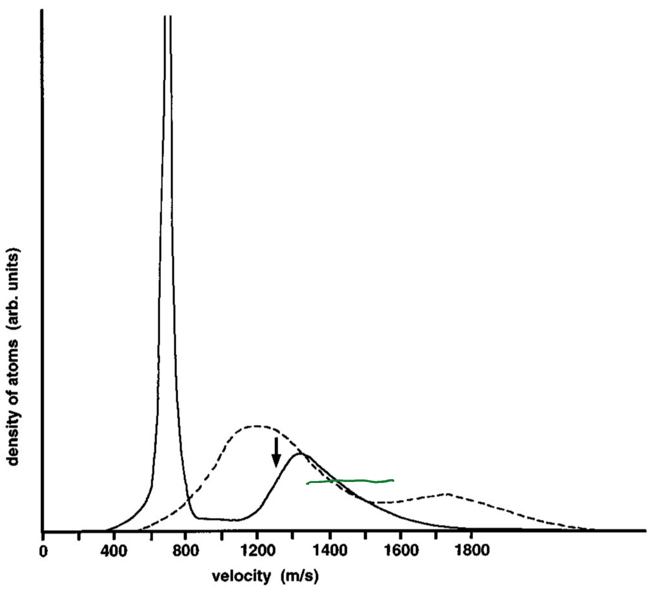
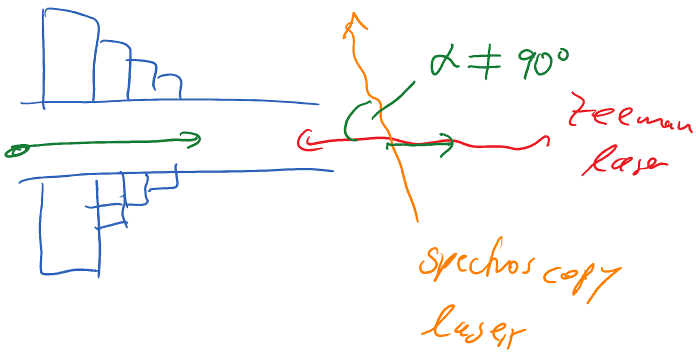




FIG. 5. Velocity distribution before (dashed) and after (solid) Zeeman cooling. The arrow indicates the highest velocity resonant with the slowing laser. (The extra bump at 1700 m/s is from $F=1$ atoms, which are optically pumped into $F=2$ during the cooling process.)

B. Philips
Nobel lecture
Rev. Mod. Phys.



Doppler effect $= v \cdot k_{spectroscopy\ laser}$

$v \cdot \cos\alpha \cdot \frac{c}{\lambda}$