Ultracold neutral atoms

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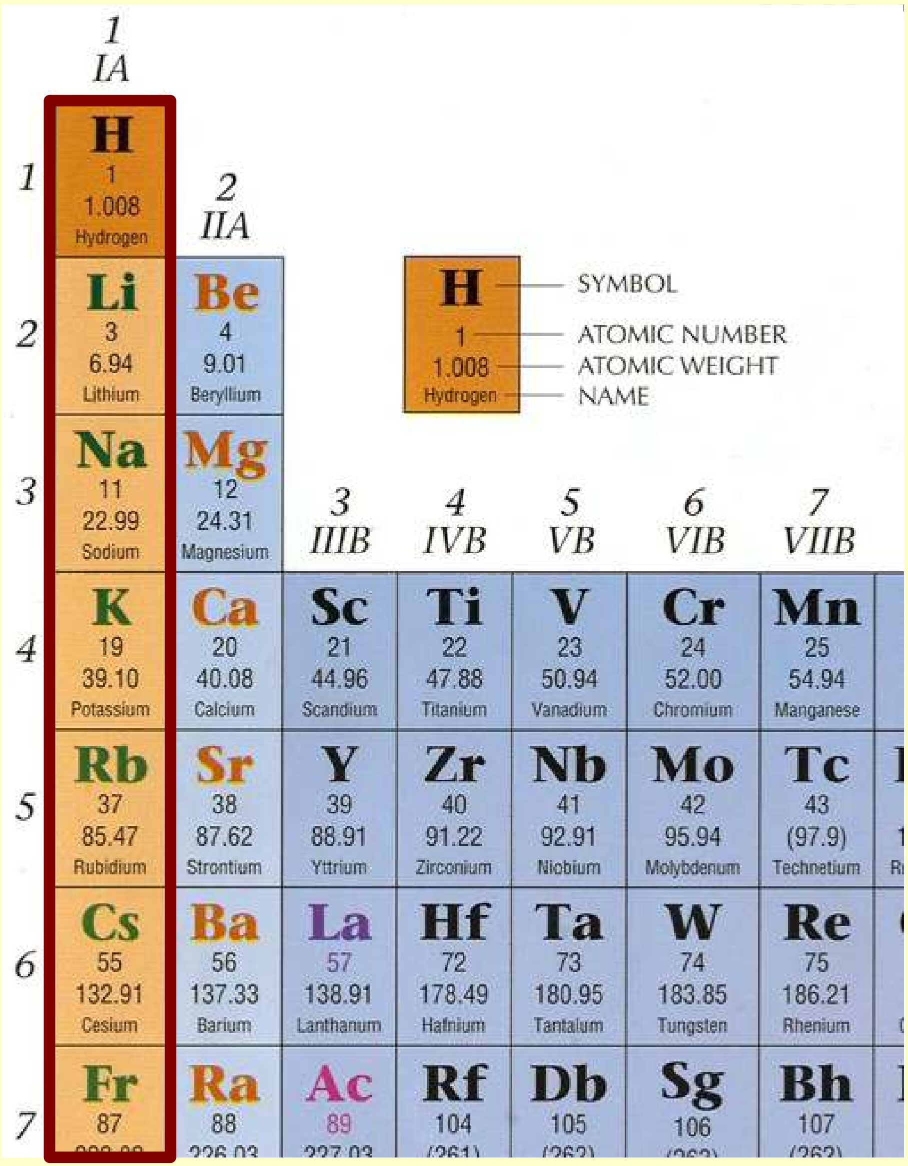
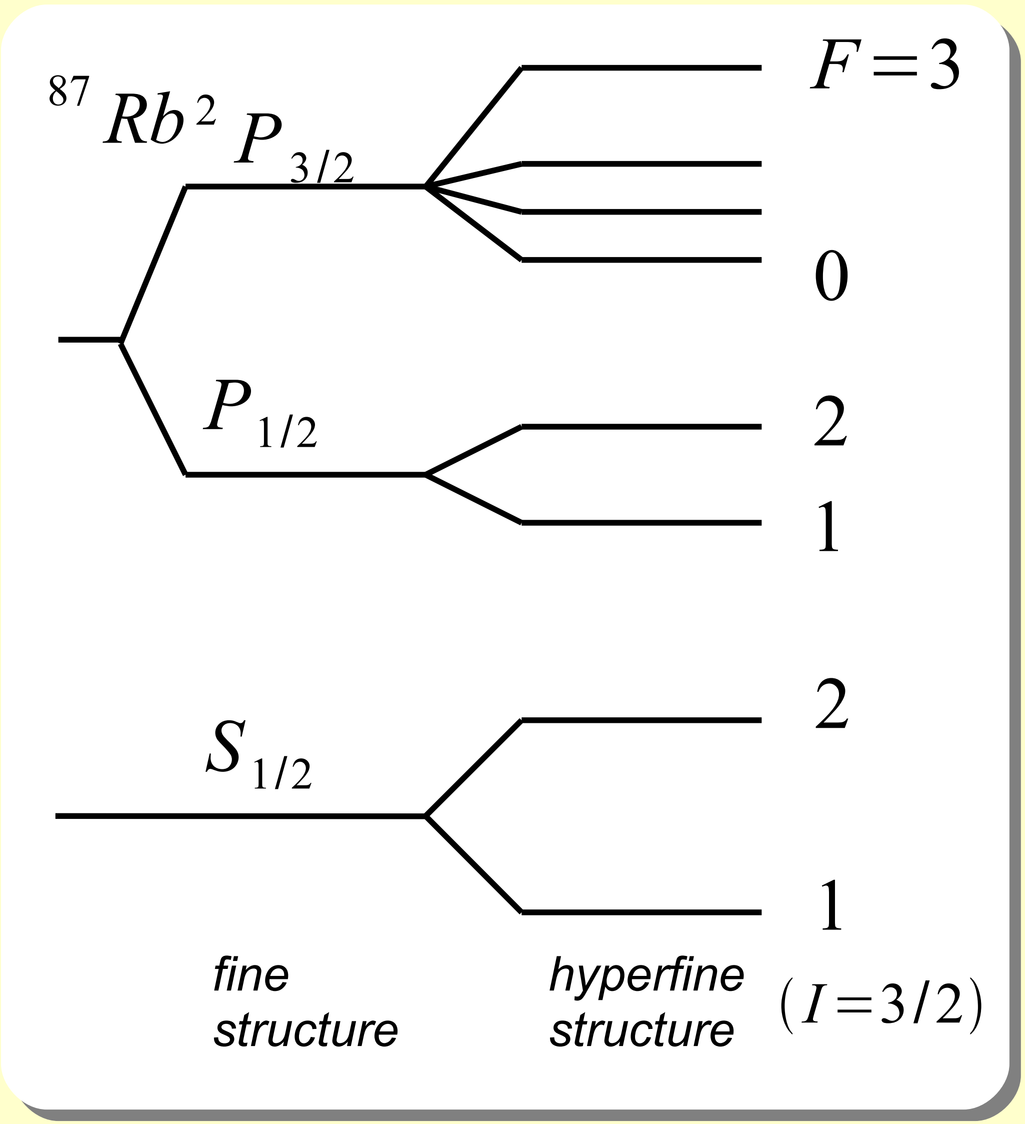
Atoms



- Instead of ions, which couple strongly to the environment, use **neutral** atoms.
- Good:
  - Long lived coherences
  - Weaker interactions
  - Less energy to trap many
    - Large, scalable
- Bad:
  - Weak interactions
  - Trapping?
  - Cooling?

Trapping

Magnetic trapping



- Hamiltonian for an atom with HFS and magnetic field

$$A\vec{J}\vec{I}+g_J\vec{J}\cdot\vec{B}+g_I\vec{I}\cdot\vec{B}$$

with

$$g_I \ll g_J$$

- This can not be diagonalized in the basis of total angular momentum

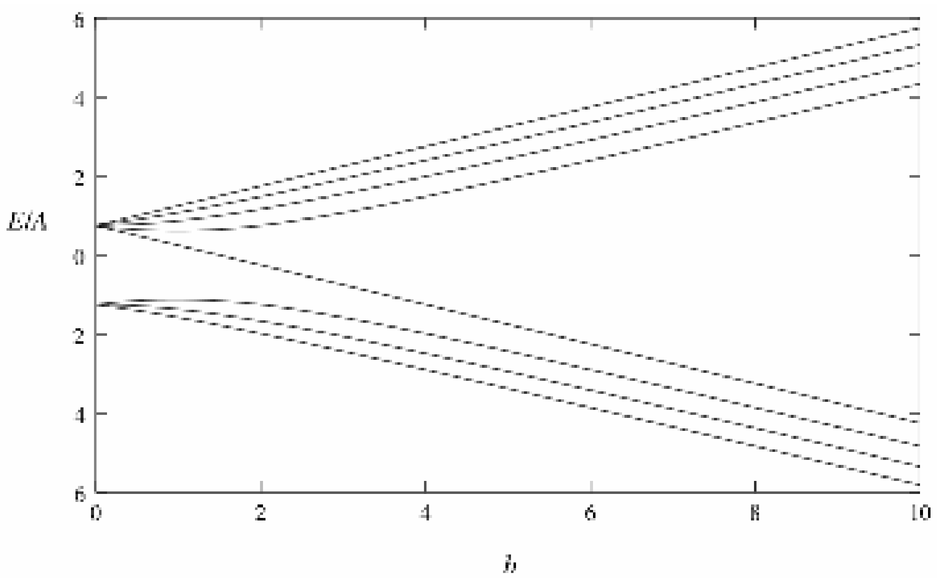
$$\vec{F}=\vec{J}+\vec{I}$$

because only

$$F_z=I_z+J_z$$

along B is conserved

Magnetic trapping



- We get a linear and quadratic Zeeman splitting

$$E_{m_F=\pm 2}=\frac{3}{4}A\pm\frac{1}{2}C$$

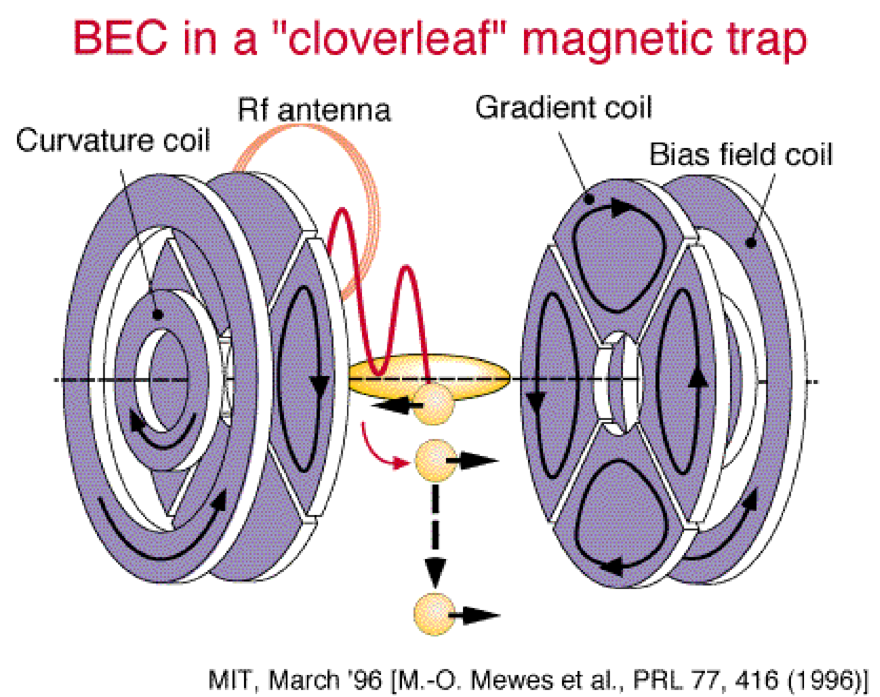
$$E_{m_F=+1}=-\frac{1}{4}A\pm\sqrt{\frac{3}{4}A^2+\frac{1}{4}(A-C)^2}$$

$$E_{m_F=-1}=-\frac{1}{4}A\pm\sqrt{\frac{3}{4}A^2+\frac{1}{4}(A+C)^2}$$

$$E_{m_F=0}=-\frac{1}{4}A\pm\sqrt{A^2+\frac{1}{4}C^2}$$

with $C=|g_J B|$

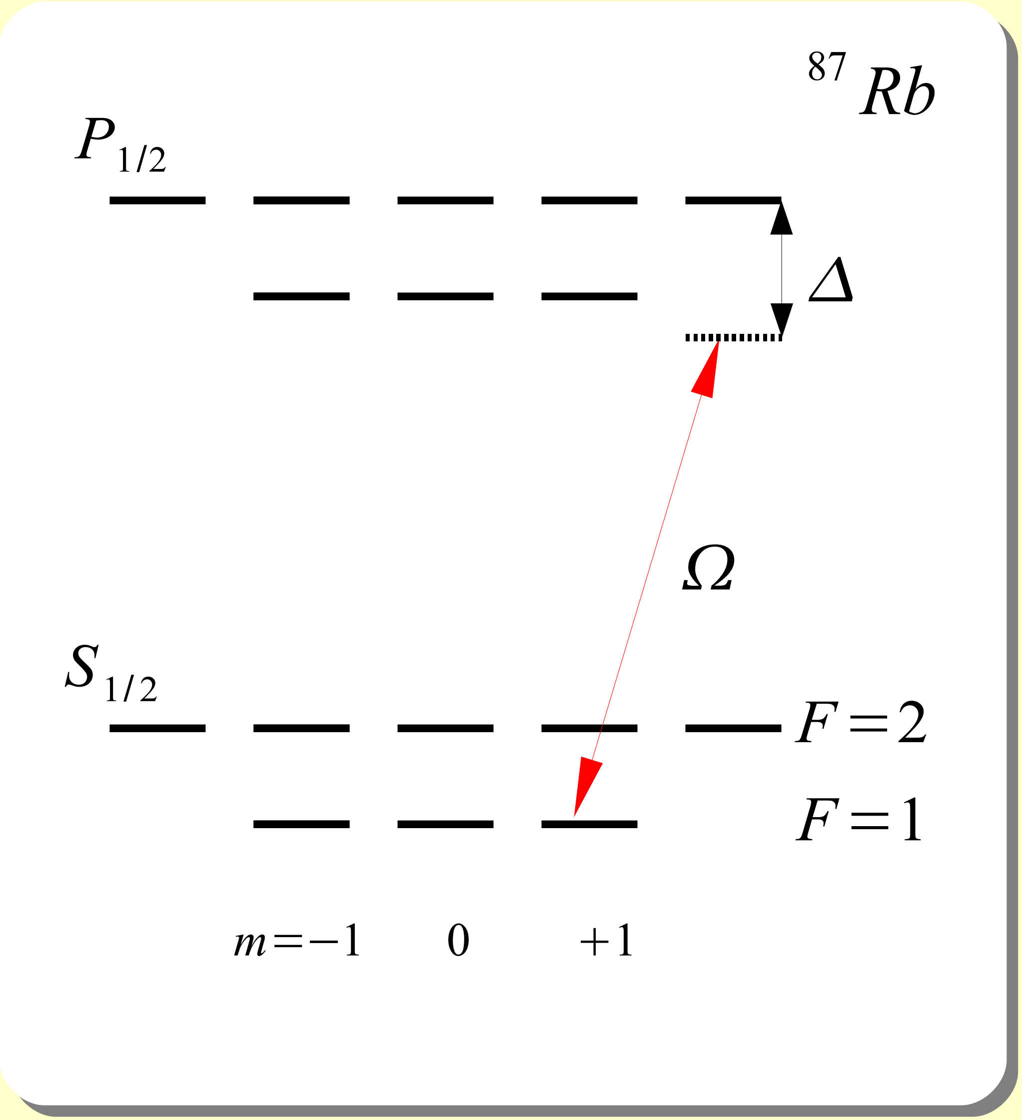
Magnetic trapping



- We can trap the low-field seekers
  - Atoms that tend towards small value of |B|
- Majorana flips: when B=0, the atom magnetic moment can flip at no cost, becoming untrapped.
- Ioffe-Pritchard and cloverleaf traps combine quadrupole potentials with coils that shift the minimum to nonzero B.

Optical trapping

Light force



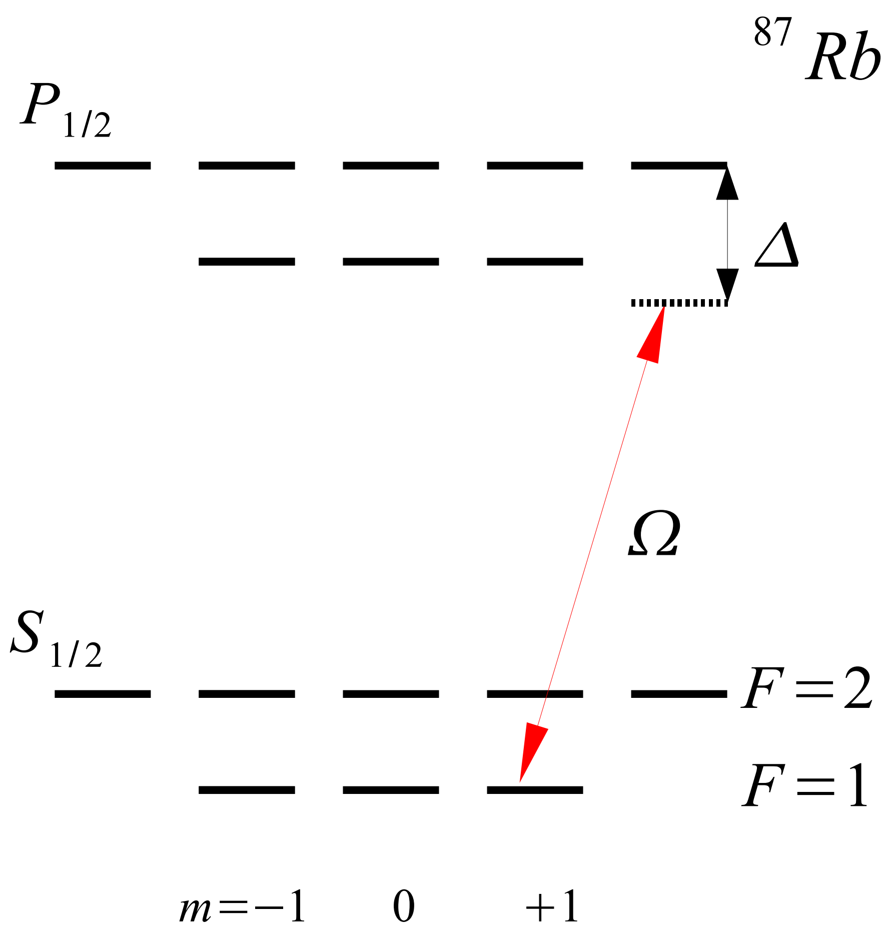
- When off-resonant light acts on an atom, it induces an energy shift
  - AC Stark shift

$$V_{AC} \sim -\frac{\Omega(x)^2}{\Delta}$$

- Second order pert. theory

$$|g\rangle\langle g|H_{l-at}|e\rangle \times \frac{1}{E_g+\hbar\omega-E_e} \times \langle e|H_{l-at}|g\rangle\langle g|$$

Light force



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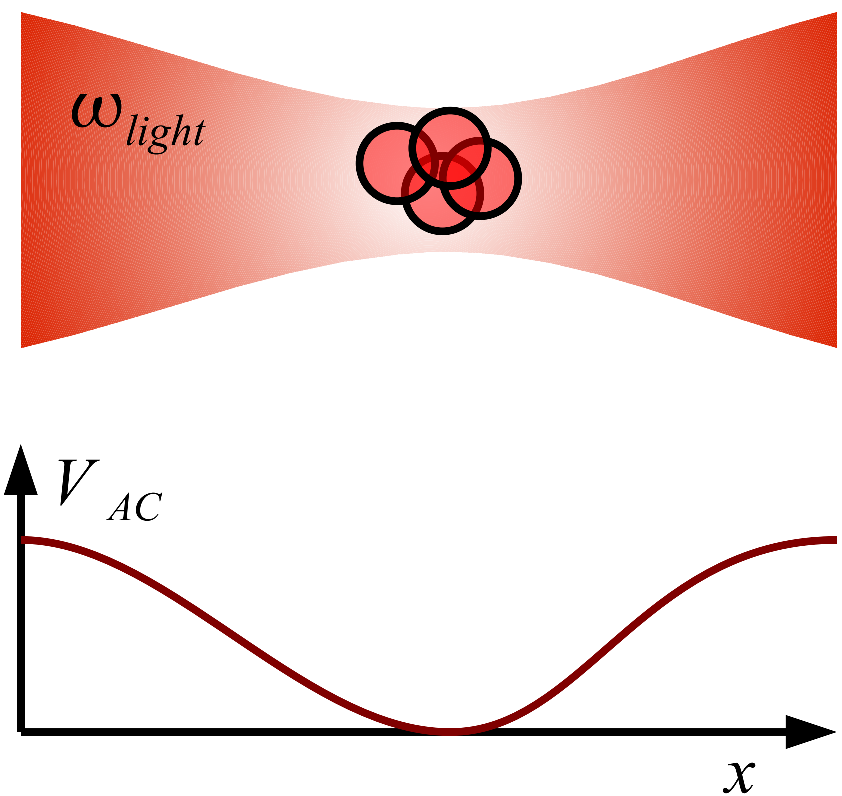
- The potential depends on the light intensity.
- Different detunings
  - **Red:** attracted to maxima
  - **Blue:** attracted to minima

Light force



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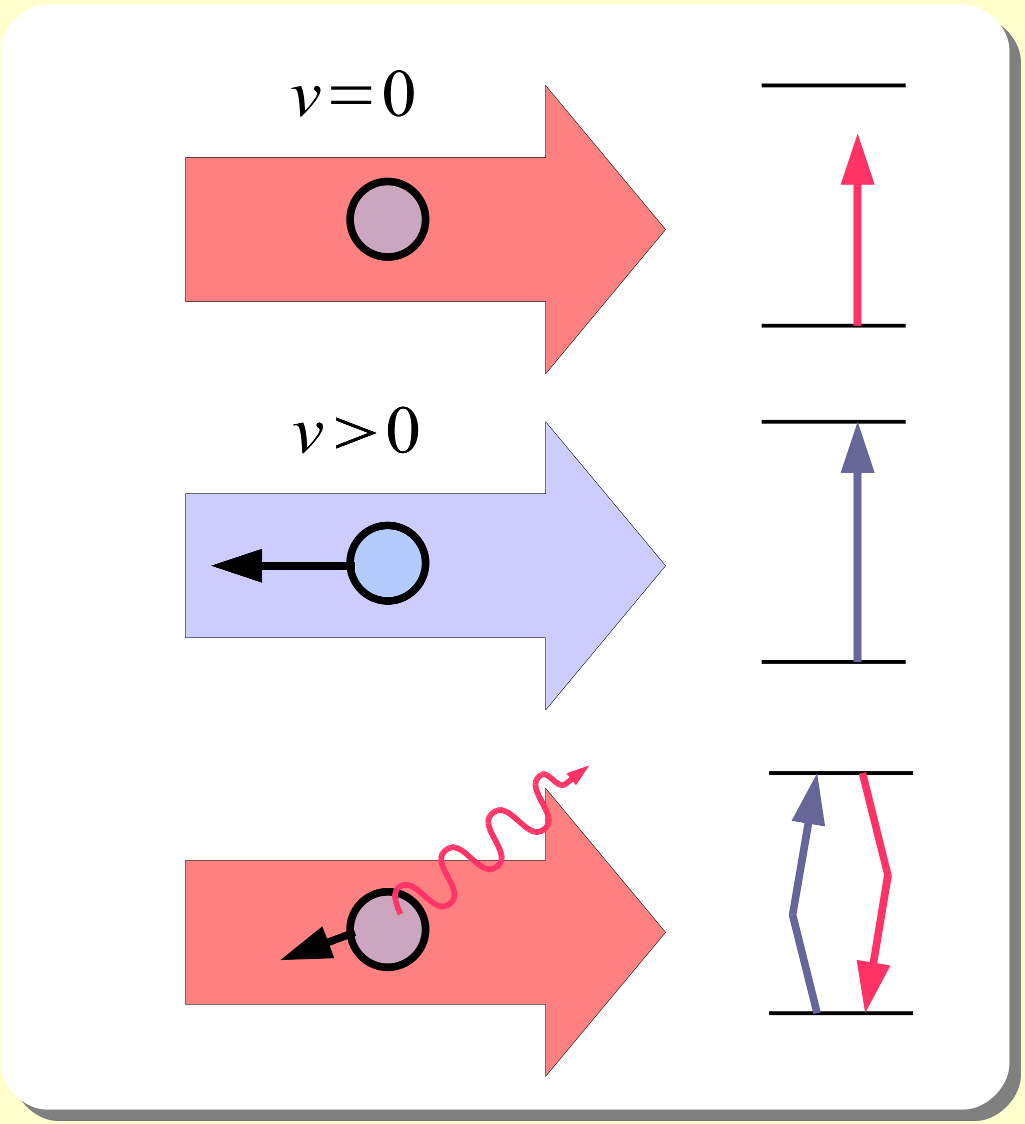
Cooling

Doppler cooling



- When an atom travels against a laser beam, it "sees" a different frequency

$$f = \left(1 - \frac{v_{at-l}}{c}\right) f_0$$

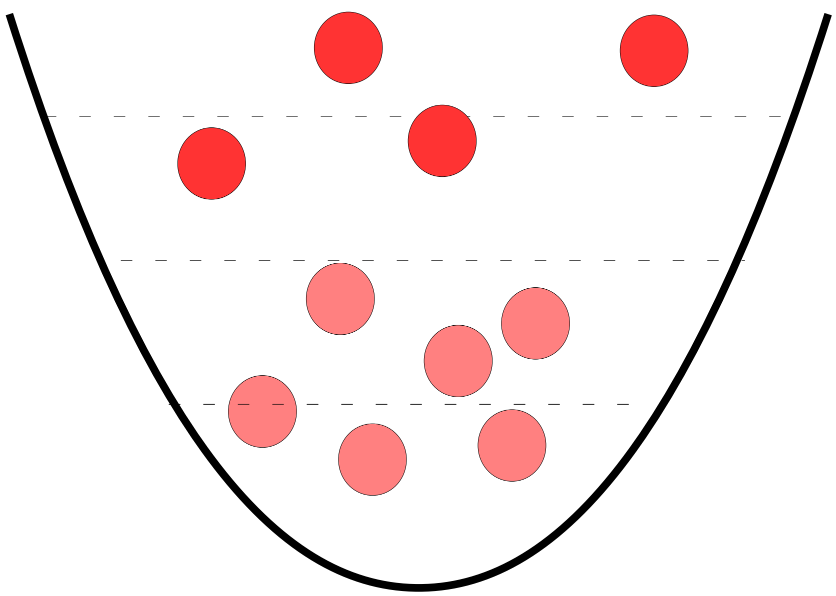
- The atom turns into resonance, absorbing a photon and slowing down.
- Photon reemitted, but avg. kinetic energy decreases.
- **Minimum temperature**

$$T_{min} = \frac{\hbar}{k_B} \gamma$$

Evaporative cooling

- Principle by which a cup of coffee cools down
  - Hotter particles evaporate, taking away energy.
- Since it is an open system, an equilibrium is reached
  - Environment temperature
- Particles are lost.

Evaporative cooling

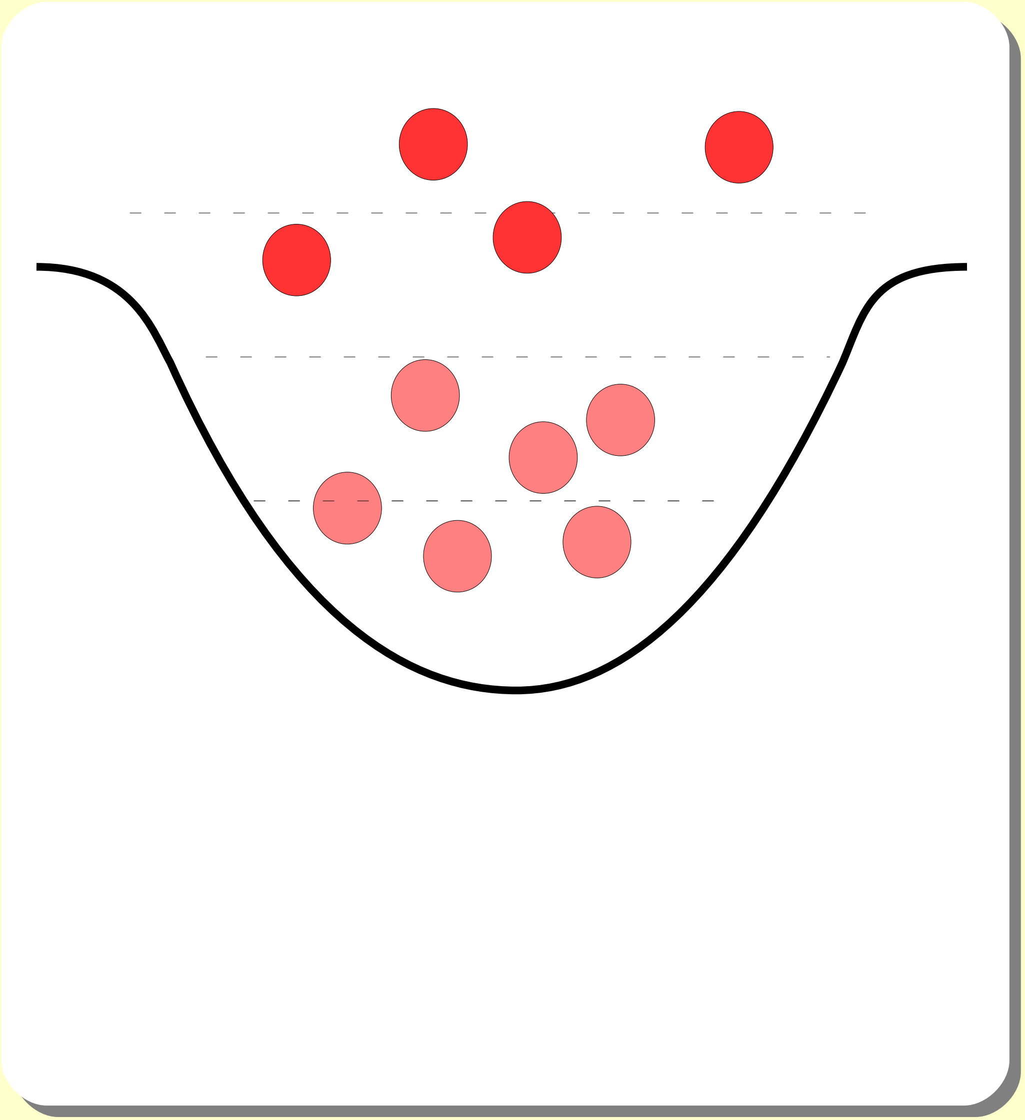


$$V(x) \sim \frac{1}{2} m \omega^2 x^2$$

$$\omega \sim 10 - 100\, Hz$$

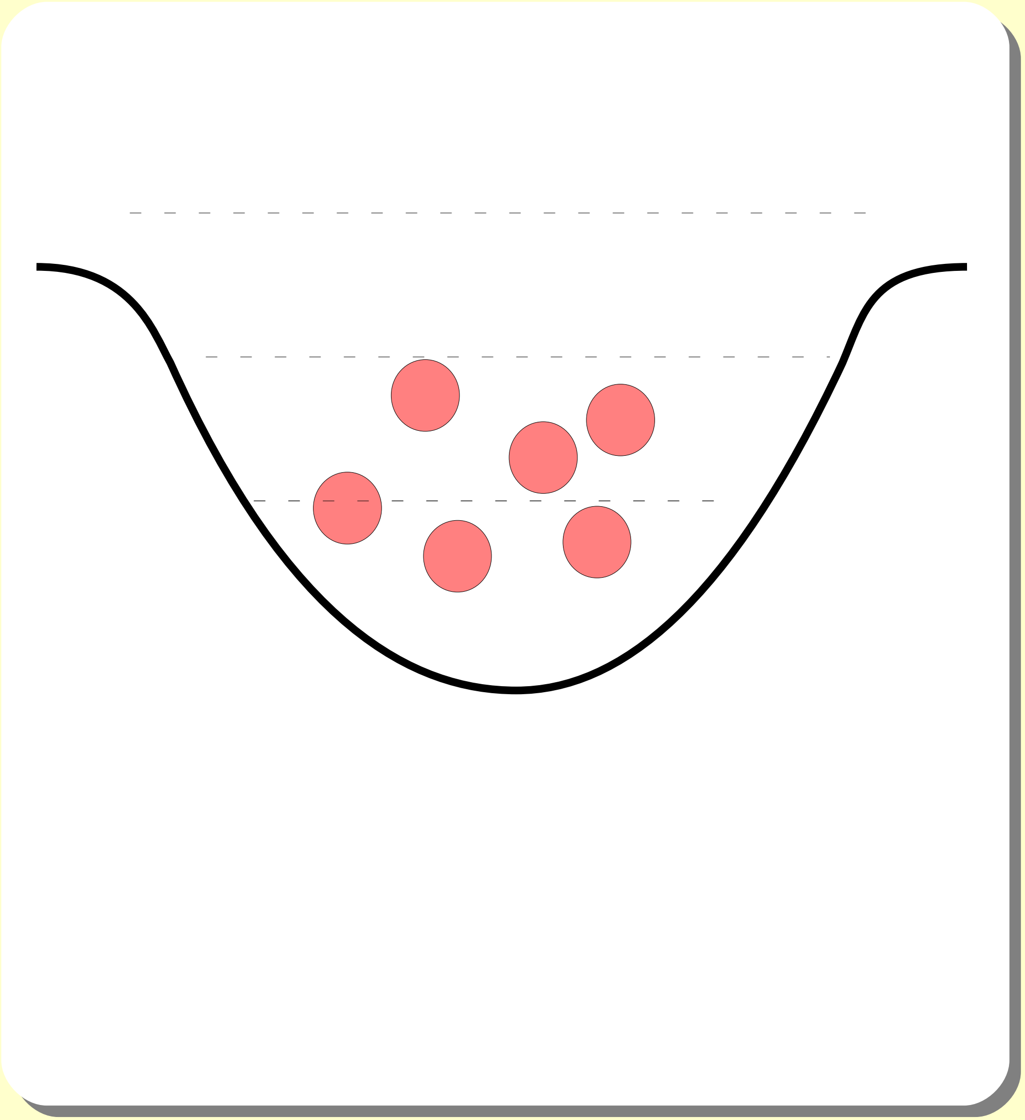
- Trap the atoms in some potential.

Evaporative cooling



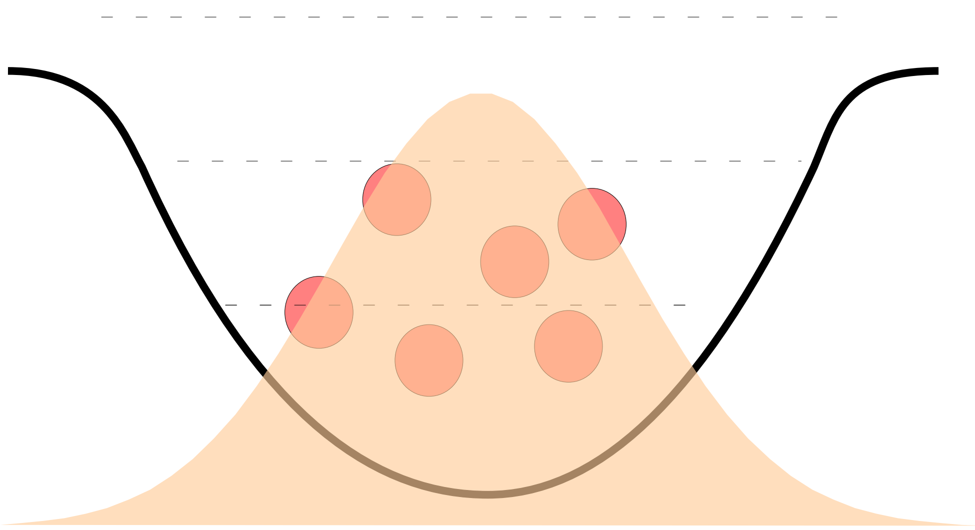
- Trap the atoms in some potential.
- Open up the potential

Evaporative cooling



- Trap the atoms in some potential.
- Open up the potential.
- Let the hotter atoms evaporate.

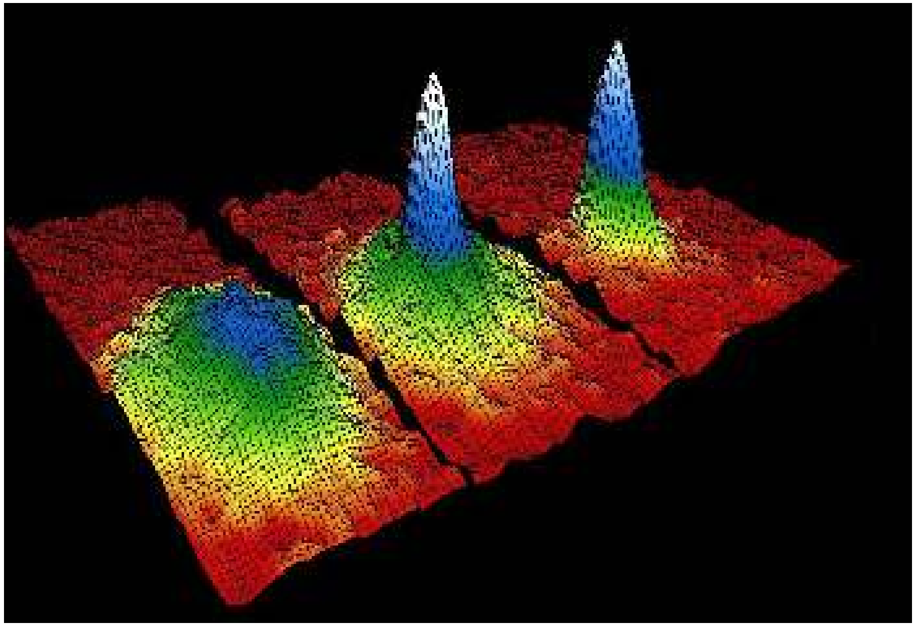
Evaporative cooling



$$\psi(x_{1,}x_{2,}\ldots)=\phi(x_1)\phi(x_2)\cdots$$

- Trap the atoms in some potential.
- Open up the potential.
- Let the hotter atoms evaporate.
- The remaining atoms thermalize to a new T.
- If density is high and temperature low, and we have bosons...
  - Bose-Einstein condensation

Bose-Einstein condesate

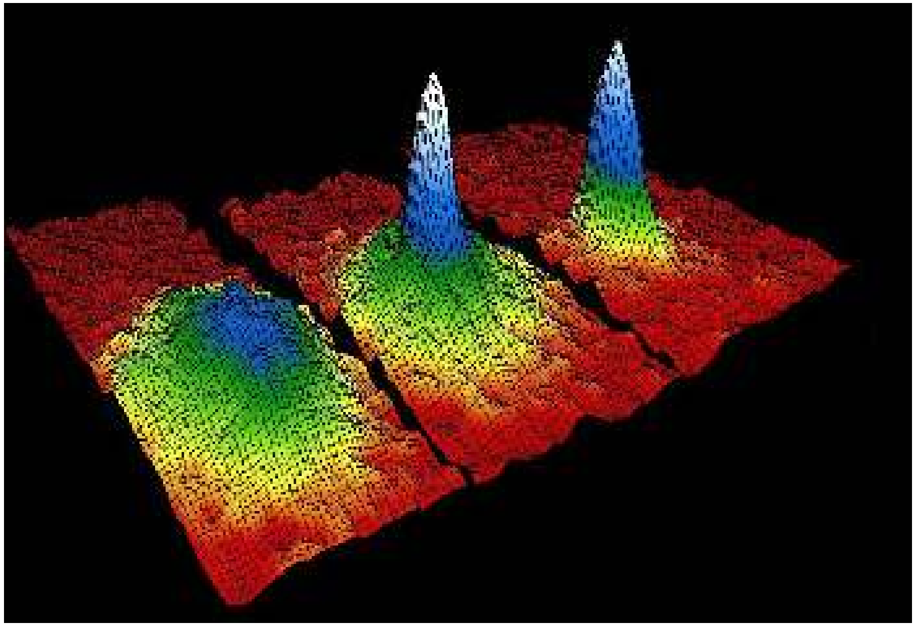


$$\psi(x_1, x_2, \ldots) = \phi(x_1)\phi(x_2)\cdots$$

=

Nobel prize!!!

Bose-Einstein condesate



$$\psi(x_{1,}x_{2,}\ldots)=\phi(x_1)\phi(x_2)\cdots$$

=

Source of ultracold atoms, with the **same motional state**. We only care about internal state now!