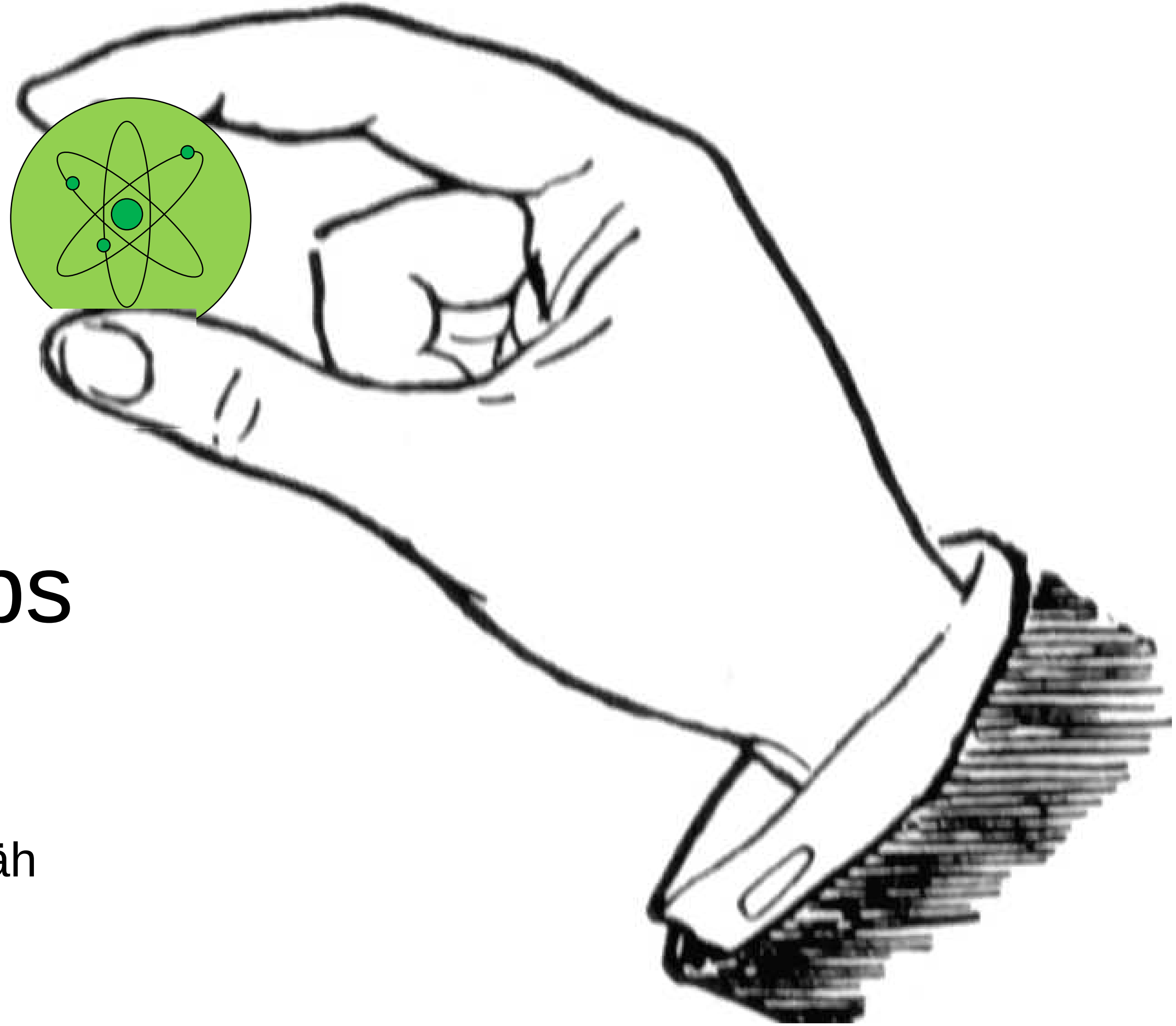
Atom meets Photon



Atom traps

(Atomfallen)

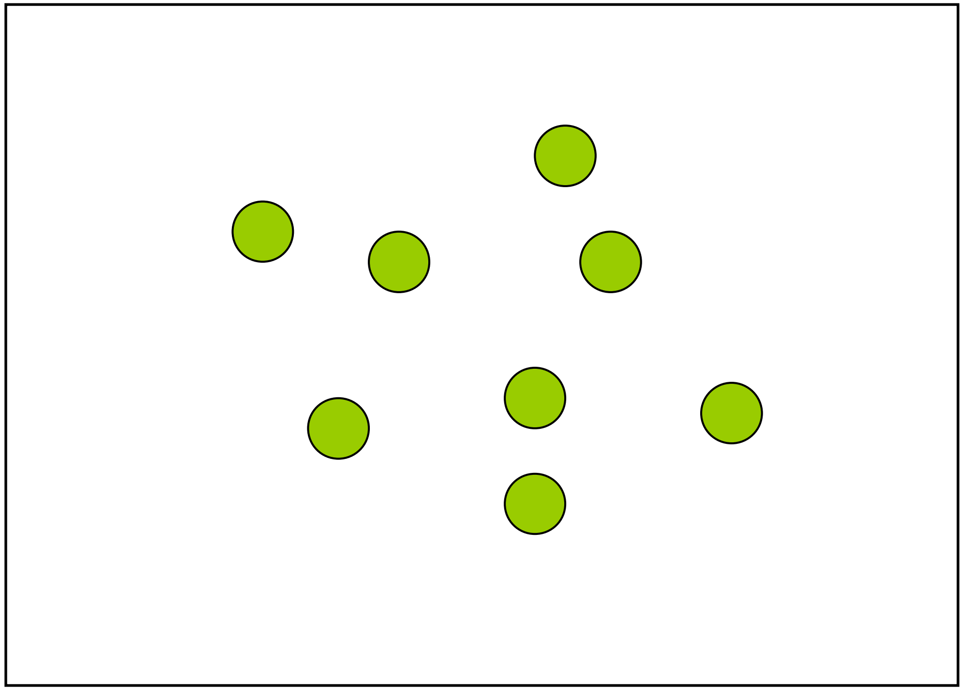
Alexander Späh

http://etc.usf.edu/clipart/4400/4465/hand_9.htm

1. atom trap

2. four different atom traps

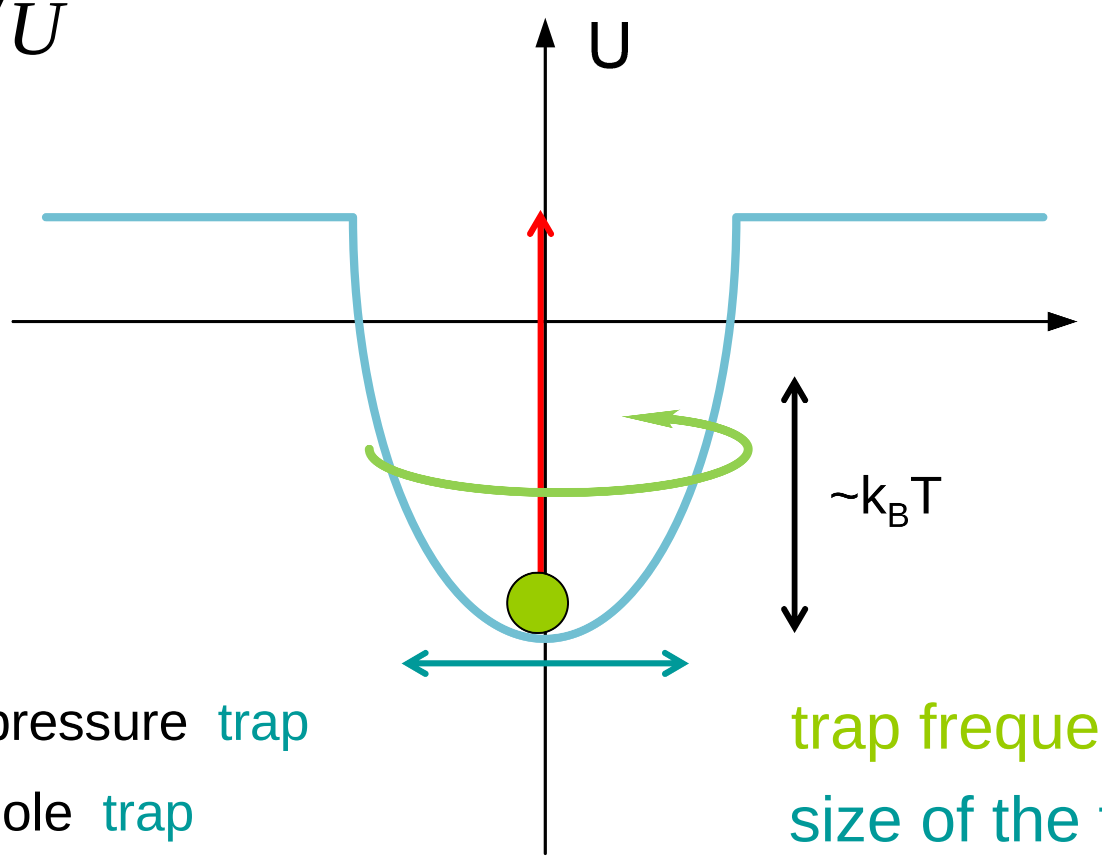
3. summary



$$E_{kin} = \frac{3}{2} k_B T$$

$$E_{pot} = ?$$

$$\vec{F} = -\nabla U$$



Forces:

radiation pressure trap

optical dipole trap

magnetic trap

electric trap

(only consider neutral atoms)

trap frequency

size of the trap

depth of the trap

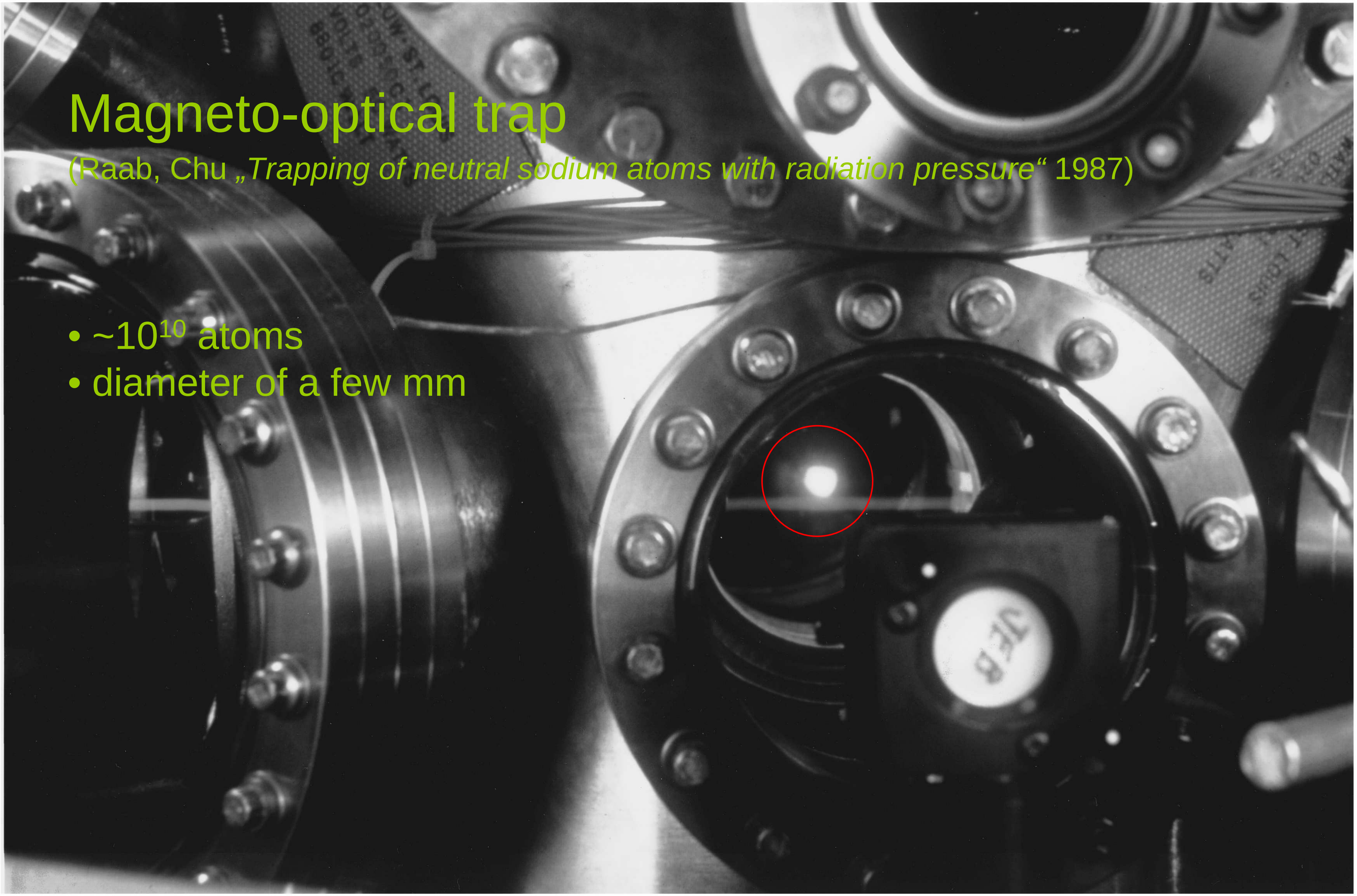
heating rate $\boxed{\dot{T}}$

time constant of the trap

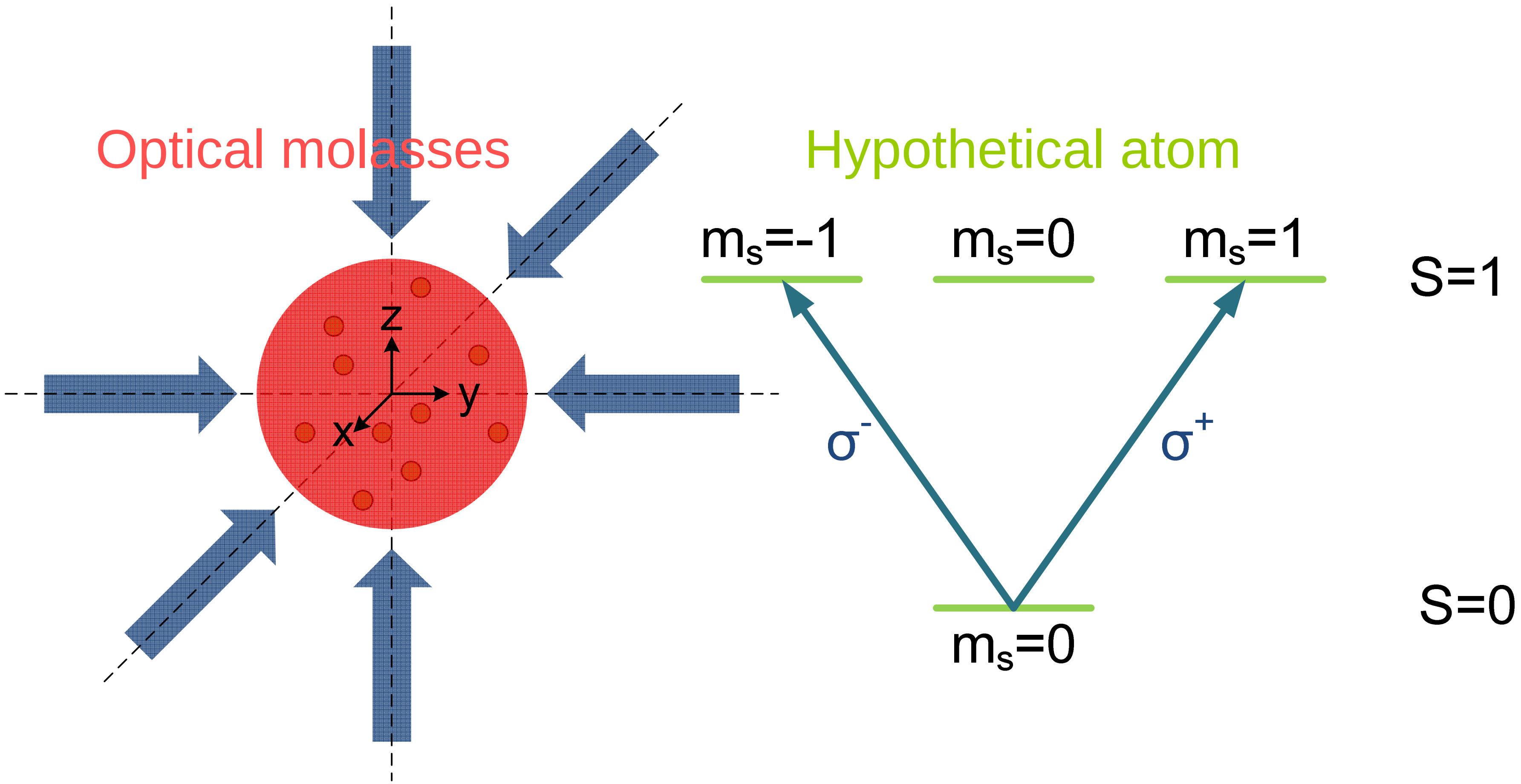
Magneto-optical trap

(Raab, Chu „*Trapping of neutral sodium atoms with radiation pressure*“ 1987)

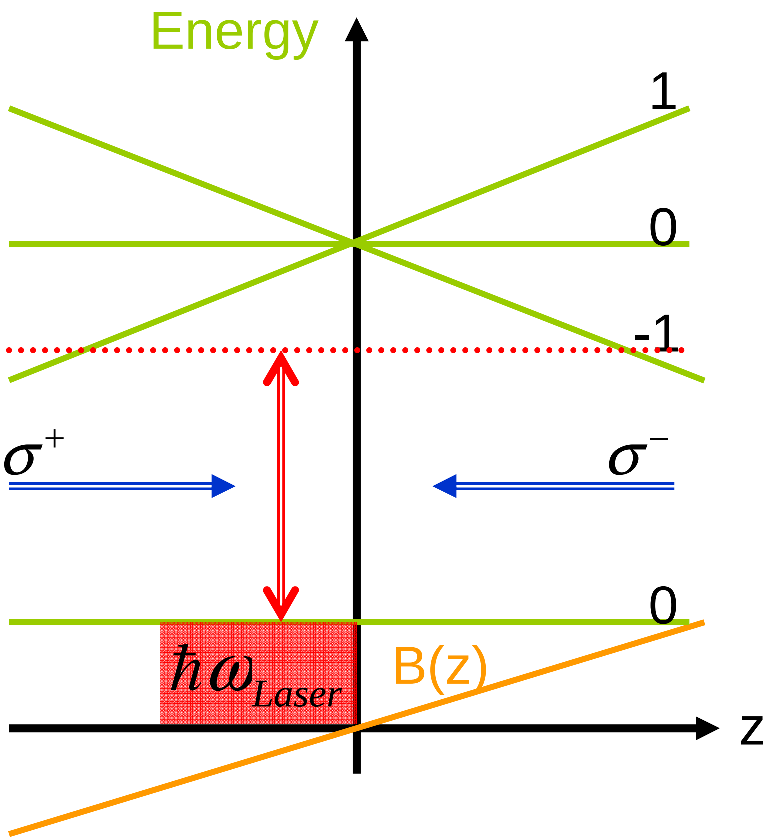
- ~10^{10} atoms
- diameter of a few mm



Chu *The manipulation of neutral particles* 1998


Optical molasses
z
y
x
Hypothetical atom
m$_s$=-1
m$_s$=0
m$_s$=1
S=1
σ$^-$
σ$^+$
m$_s$=0
S=0

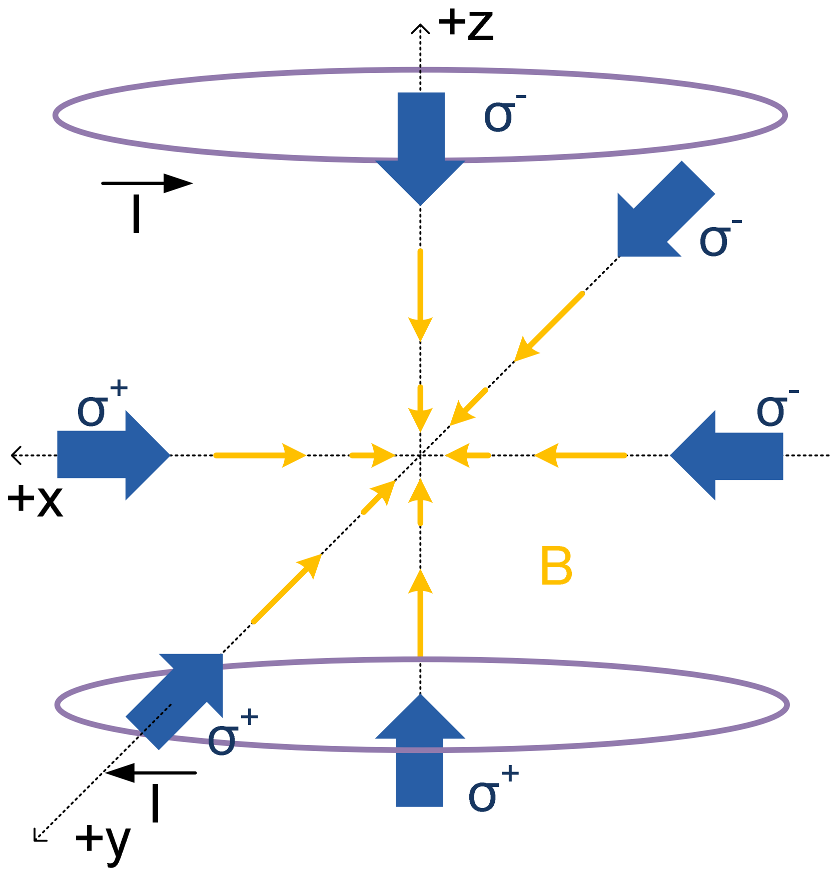
1dim case:



inhomogeneous magnetic field

$$\boxed{B(z)=bz} \longrightarrow \Delta E = \mu m_s B = \mu b m_s z$$

3dim case:



advantages:

- cooling and trapping
- cooling down to ~10µK
- capture velocity of a few K

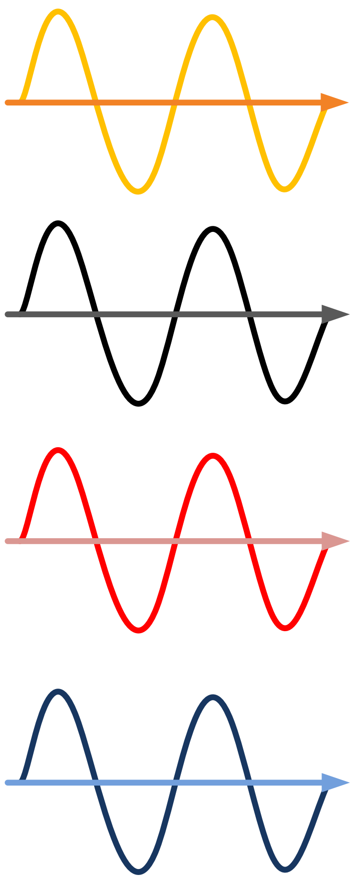
disadvantages:

- near resonant light → perturbed internal dynamics
- achievable density limited by photon reemission and reabsorbtion
- certain requirements to atom sturcture

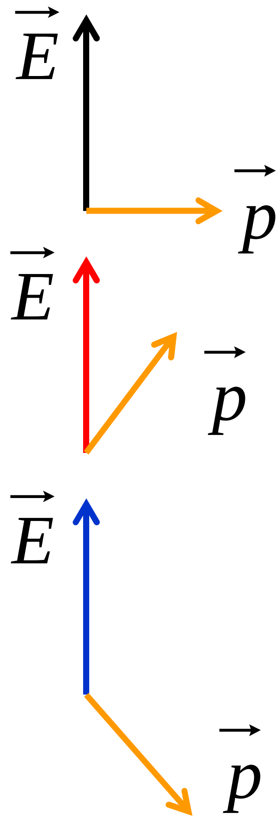
heating:

- temperature limited by doppler effects
- background pressure

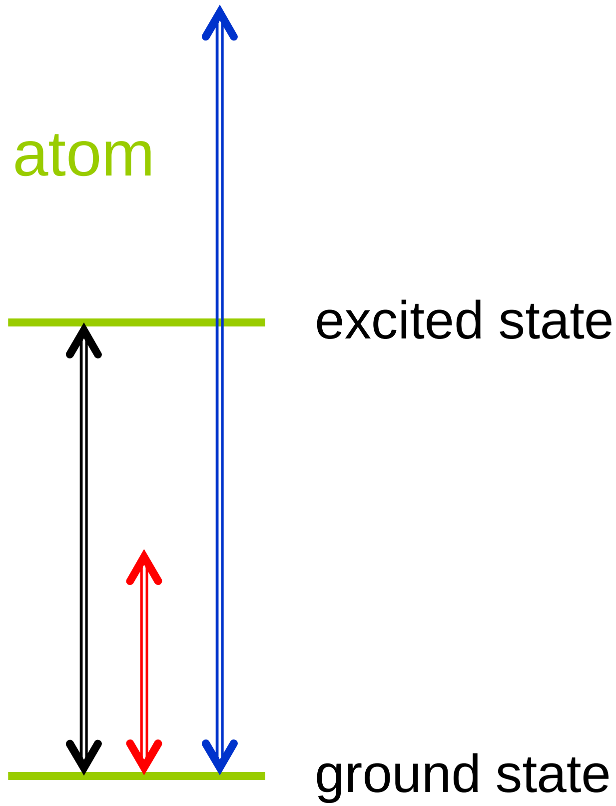
Chu *Experimental observation of optically trapped atoms* 1986 driving field E



$$U_{dip} = -\frac{1}{2}\left\langle \vec{p}\vec{E} \right\rangle$$



atom

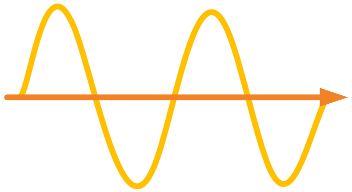


ω_0 = transition frequency

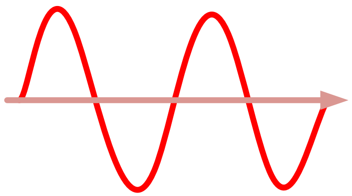
$\omega < \omega_0$ = red detuned

$\omega > \omega_0$ = blue detuned

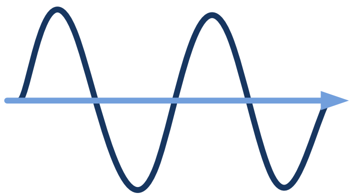
driving field E



$$U_{dip} = -\frac{1}{2}\left\langle \vec{p}\vec{E} \right\rangle \qquad \overrightarrow{F_{dip}}\left(\vec{r}\right) = -\nabla U_{dip}\left(\vec{r}\right)$$



$$U_{dip}^{red} \propto -I \qquad \overrightarrow{F_{dip}^{red}} \propto \nabla I$$



$$U_{dip}^{blue} \propto +I \qquad \overrightarrow{F_{dip}^{blue}} \propto -\nabla I$$

$$\overrightarrow{F_{dip}^{red}} \propto \nabla I \qquad\qquad \overrightarrow{F_{dip}^{blue}} \propto -\nabla I$$

red-detuned trap attracts atoms towards the max. of intensity

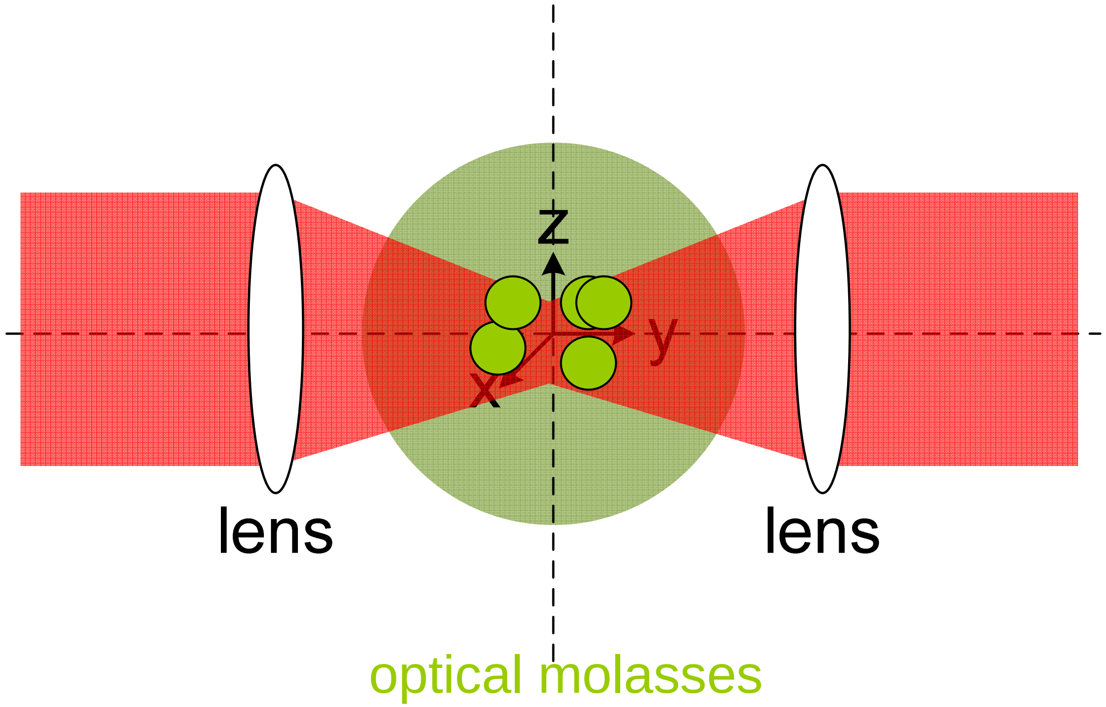
blue-detuned trap repels atoms out of intensity maximum

dipole potential $U_{dip}(\vec{r}) \propto \frac{I(\vec{r})}{\Delta}$

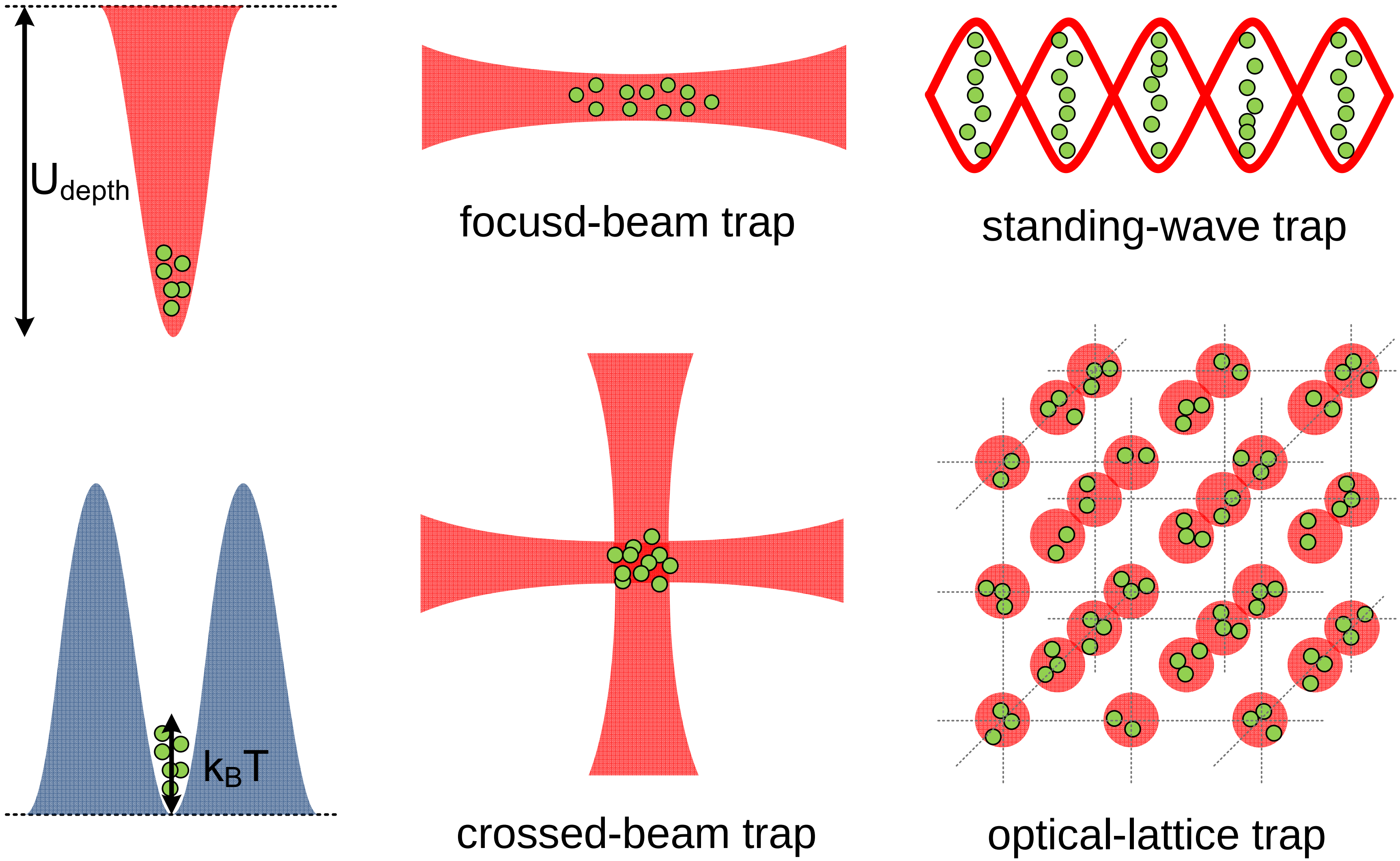
scatteringrate $\Gamma_{sc}(\vec{r}) \propto \frac{I(\vec{r})}{\Delta^2}$

$\Bigg\}$ large detunings $\Delta = \omega - \omega_0$ and high intensities for large potential depth and low scatteringrate first dipol-trap 1986 Chu (Nobel prize 1997)

(Chu „*Experimental observation of optically trapped atoms*“ 1986)



- sodium atoms cooled in optical molasses below 10^{-3}K
- laserbeam tuned far away from resonance
- ~500 atoms confined in a volume of 10^3 µm^3
- trap lifetimes of several seconds



U_{depth}
focusd-beam trap
standing-wave trap
k_BT
crossed-beam trap
optical-lattice trap

advantages:

- far-detuned light causes weak interacion and therefore optical excitation can be kept very low
- trapping times of many seconds
- great variety of different trapping geometries
- easily moveable

disadvantages:

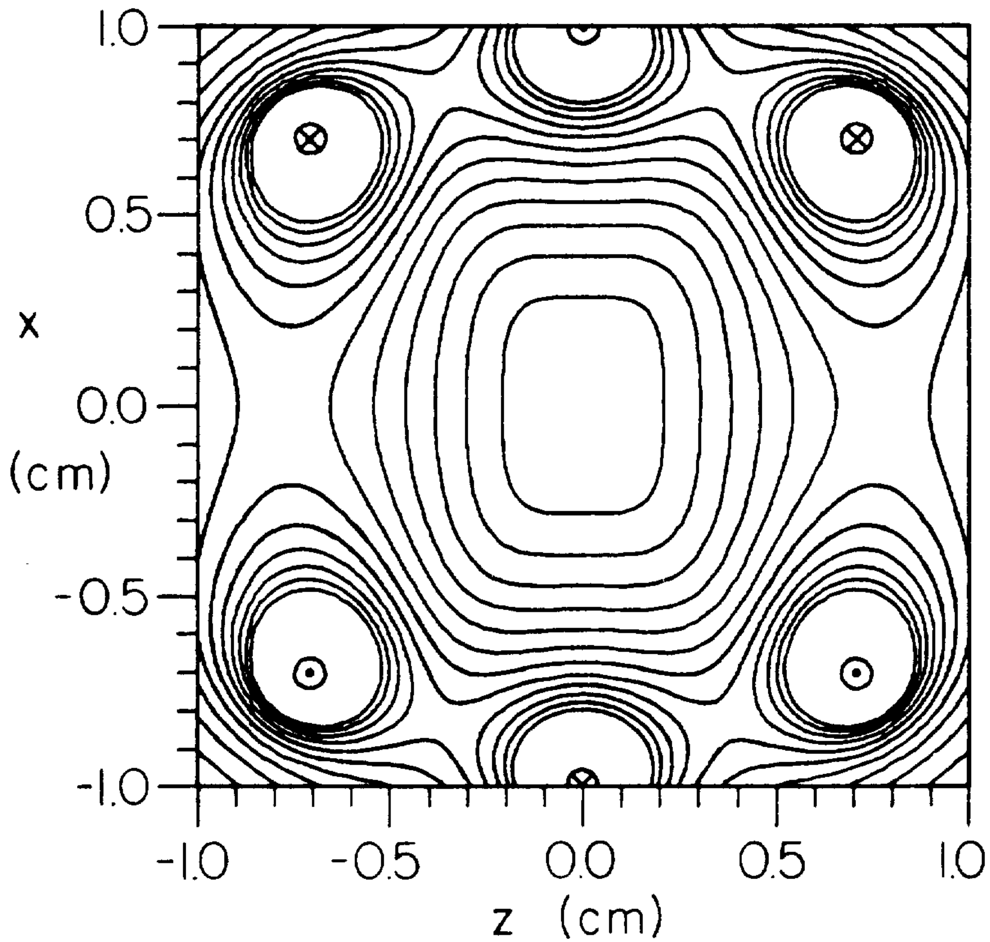
- loading with precooled atoms
- no cooling

heating:

- scattering processes
- red-detuned trap: atoms at intensity maximum
- blue-detuned trap: atoms at intensity minimum
- background pressure

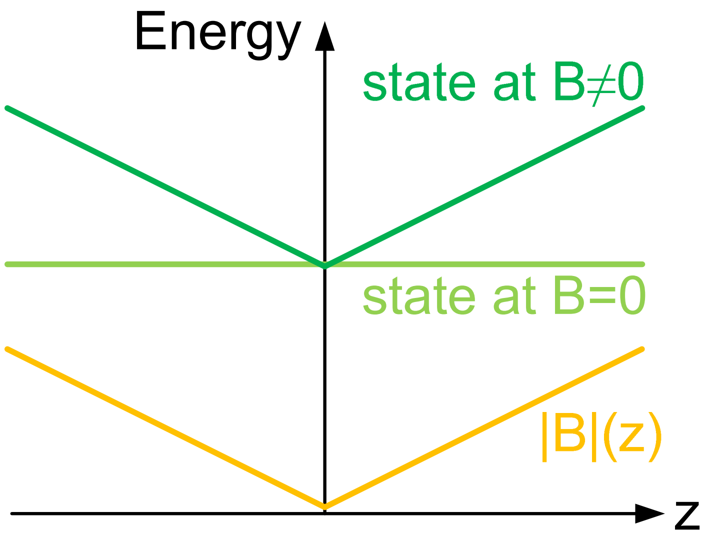
Magnetic trap

(Alan „First observation of magnetically trapped neutral atoms“ 1985)



T. Bergeman *magnetostatic trapping fields for neutral atoms* 1987

1dim:



magnetic potential

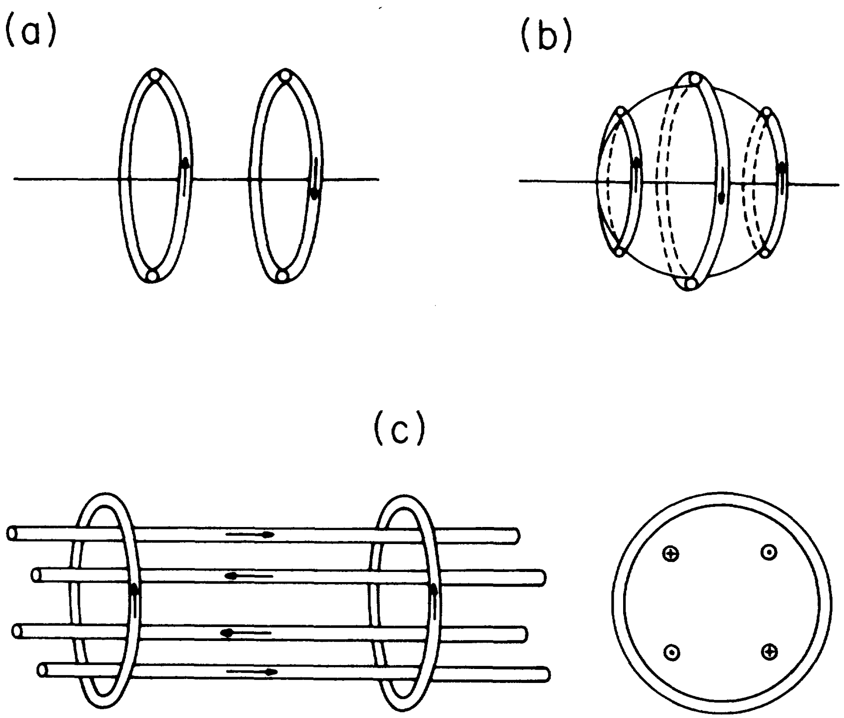
$$U_{mag} = \mu \left| \vec{B} \right|$$

(e.g. Na $3S_{1/2}$ $m_F=2$)

magnetic force

$$\overrightarrow{F_{mag}} = -\nabla U_{mag} = -\mu \nabla \left| \vec{B} \right|$$

Maxwell: $\vec{\nabla} \cdot \vec{B} = 0$ only low-field seekers are possible configurations of the inhomogeneous magnetic field in 3dim



(a) magn. quadrupol trap (b) spherical hexapole trap (c) ioffe trapp

T. Bergeman *magnetostatic trapping fields for neutral atoms* 1987

advantages:

- trap depths of ~100mK
- excellent tools for evaporative cooling and Bose-Einstein condensation

disadvantages:

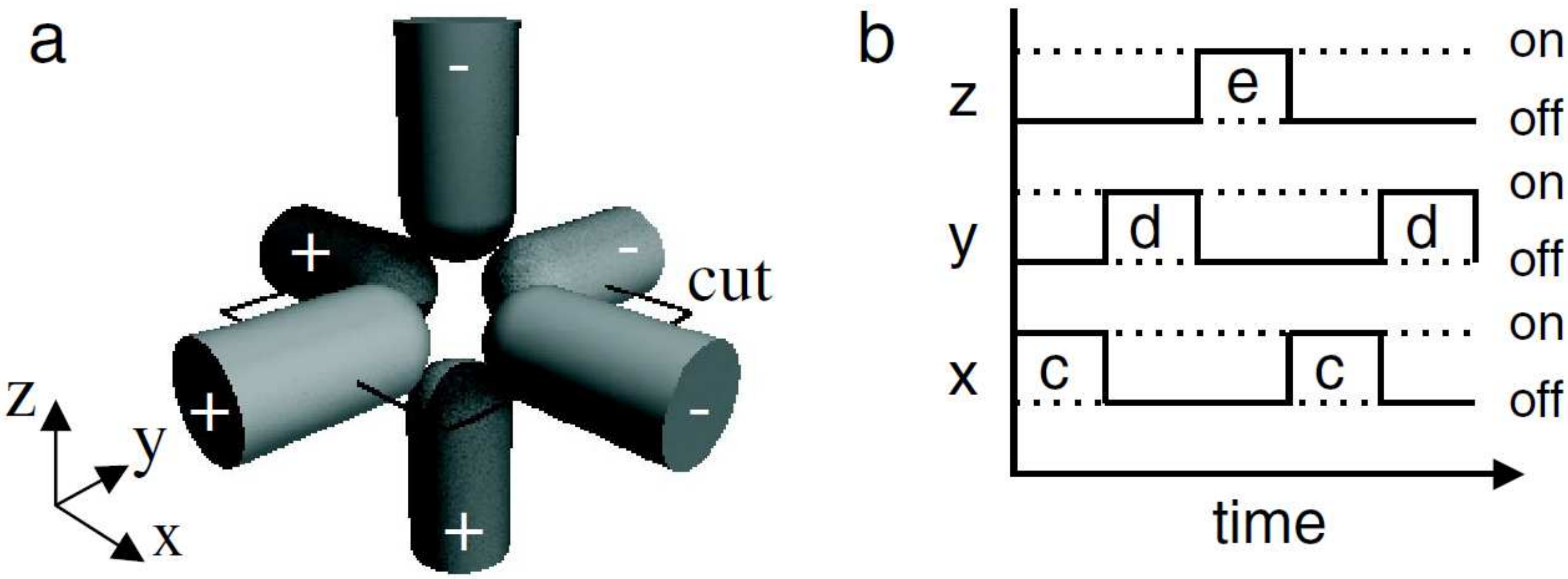
- trapping mechanism relies on the internal atomic state (only low-field seeker)
- complicated geometries of the magnetic field

heating:

- background pressure
- Majorana transitions

Electric trap

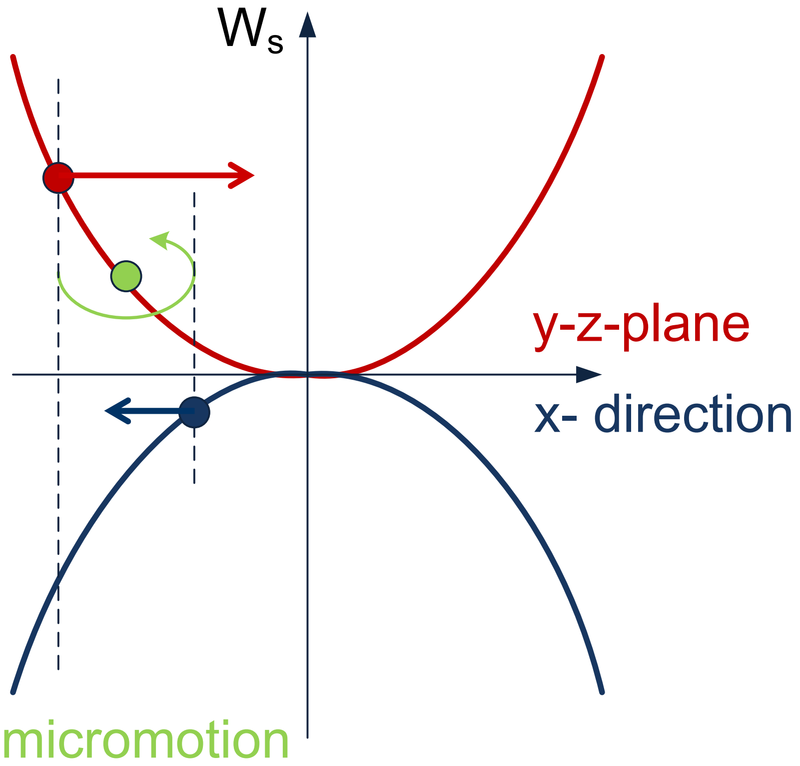
(Rieger, Rempe *„Trapping of neutral rubidium with a macroscopic three-phase electric trap“* 2007)



Rieger *Trapping of Neutral Rubidium with a Macroscopic Three-Phase Electric Trap* 2007

quadratic Strark shift $W_s = -\frac{1}{2}\alpha|E|^2$ α is the atom‘s static polarizability force $\overrightarrow{F_{el}} = -\nabla W_s = \alpha |E| \nabla |E| \cong \alpha E_0 \nabla |E|$

with $|E| = E_0 + bx^2 - \frac{1}{2} b\left(y^2 + z^2\right)$ vanish in time average



induced micromotion

$$m\ddot{x} = \sin(\omega t)$$

$$x \propto -\sin(\omega t)$$

non-linear potential and micromotion
cause net force towards the trap center

advantages:

- confining molecules and atoms
- trap size of 0.3mm in diameter

disadvantages:

- ~20µK trap depth
- need precooled atoms

heating:

- background preassure

	MOT	Dipole	Magnetic	Electric
advantages	• cooling • trapping from thermal gases	• far-detuned light • many trapping geometries • red and blue detuning	• depths of ~100mK • Bose-Einstein condensation	• molecules and atoms
disadvantages	• near resonant light	• loading with precooled atoms	• only low-field seeker	• ~20µK trap depth
heating	• temperature limited by doppler effects	• scattering processes • different heating for red and blue detuning	• Majorana transitions	• background pressure