INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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WINTER COLLEGE ON HIGH RESOLUTION SPECTROSCOPY

(8 January - 2 February 1990)

ELECTROMAGNETIC TRAPS FOR NEUTRAL ATOMS

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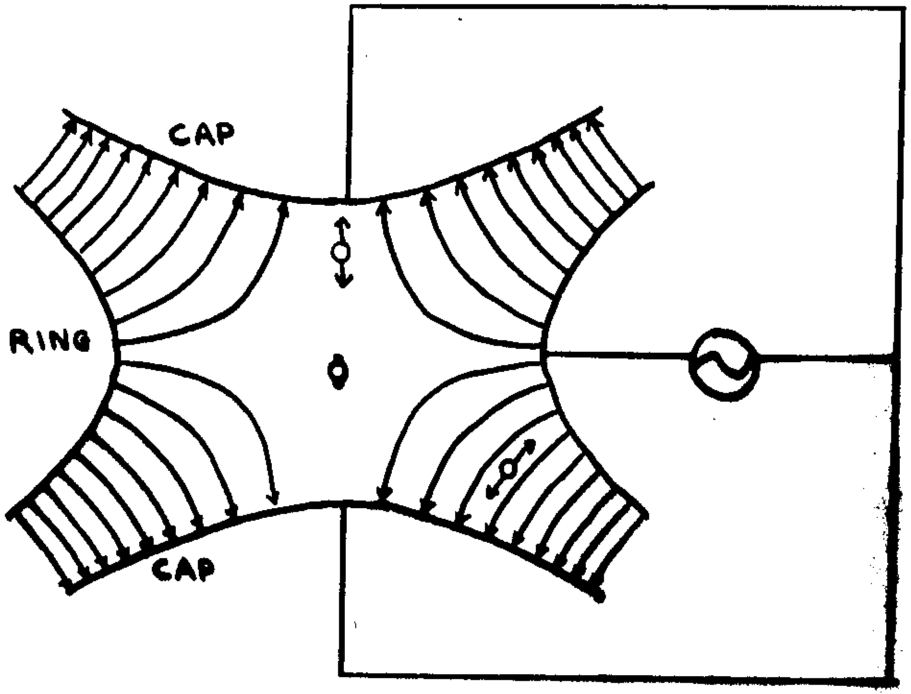
U.S.A.

ION TRAPS (rf)



Deep Trap
Long Storage Time

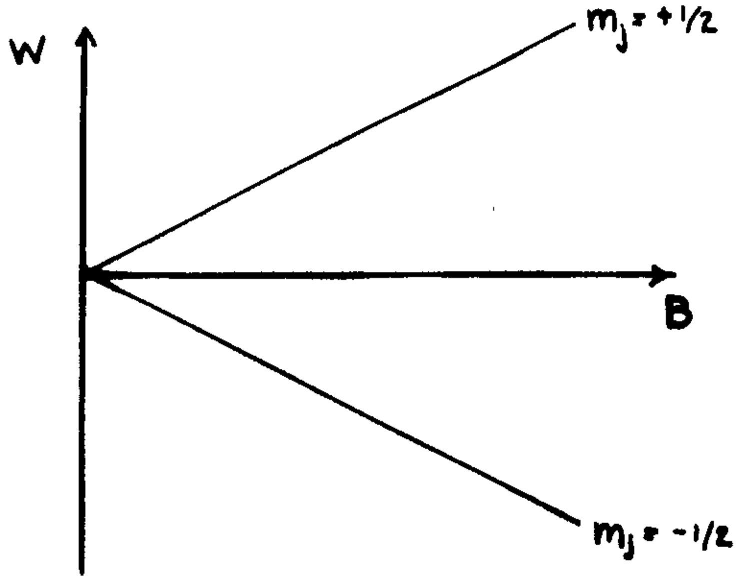
Neutral Atom Traps

- Magnetic
- Optical
  - Gradient Force
  - Radiation Pressure (Scattering) Force
- Electrostatic
- Hybrid
- Stable Traps are too Shallow (≈1K) to hold most thermal atoms!

Depth of Magnetic Traps

Early ideas:
W. Paul } 1960
C.V. Heer

First atom trap:
NBS 1985



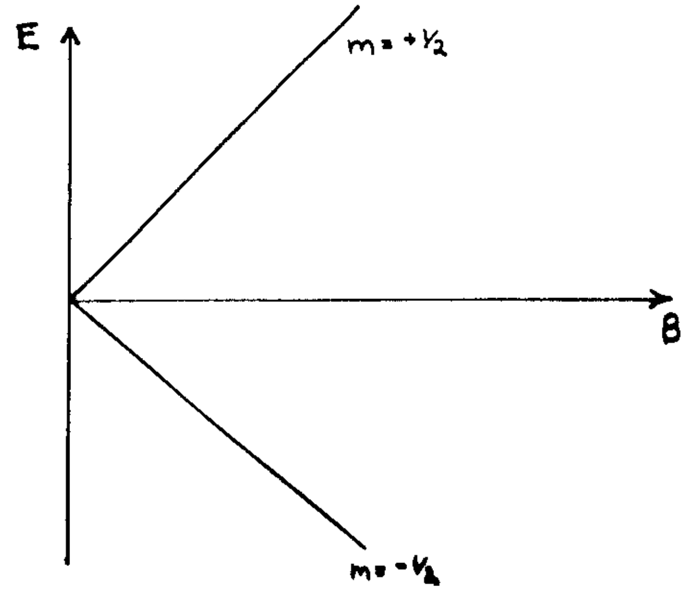
$W = -\vec{\mu} \cdot \vec{B}$

For $|\vec{\mu}| = 1$ Bohr Magneton
(typical for ground state)

For $B = 20$ KGauss, $W = 1.3$ K, $v = 30$ m/s

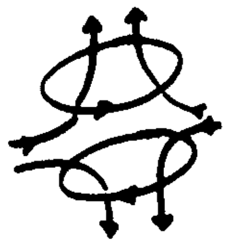
$B = 200$ Gauss, $W = 13$ mK, $v = 3$ m/s

Magnetostatic Trapping



$2T \Rightarrow \sim 1.5$ K

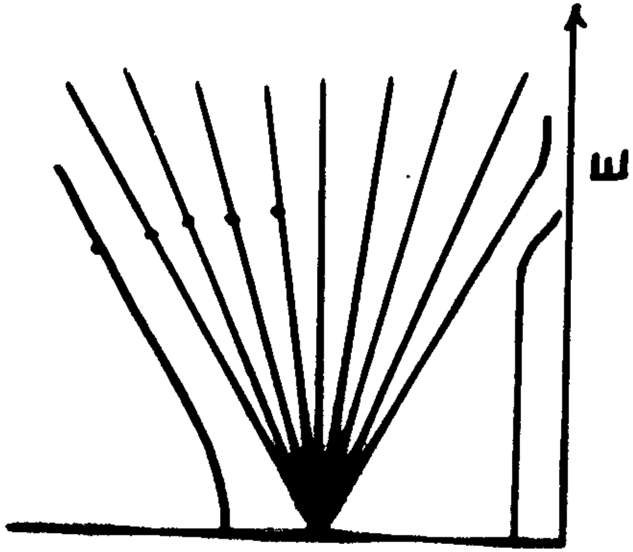
Magnet Traps: early ideas W. Paul ~1960
C.V. Heer

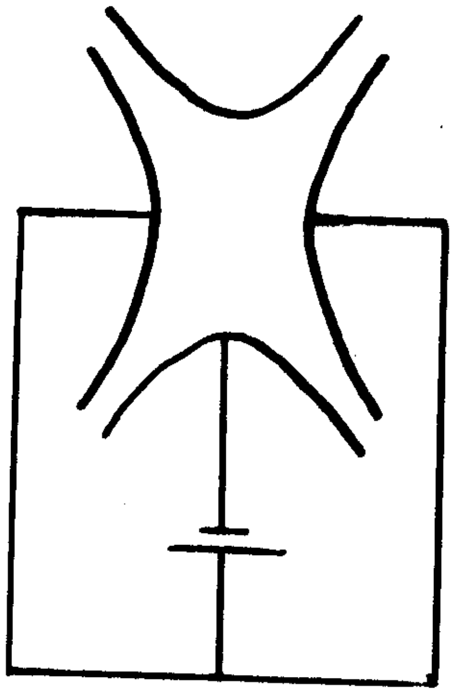


First atom trap:
NBS 1985

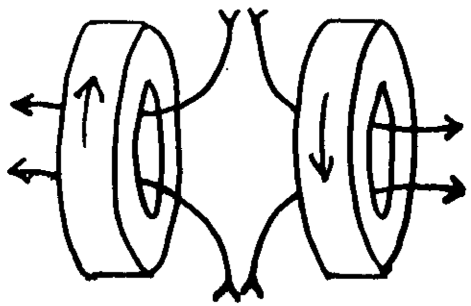
Electrostatic Atom Trap

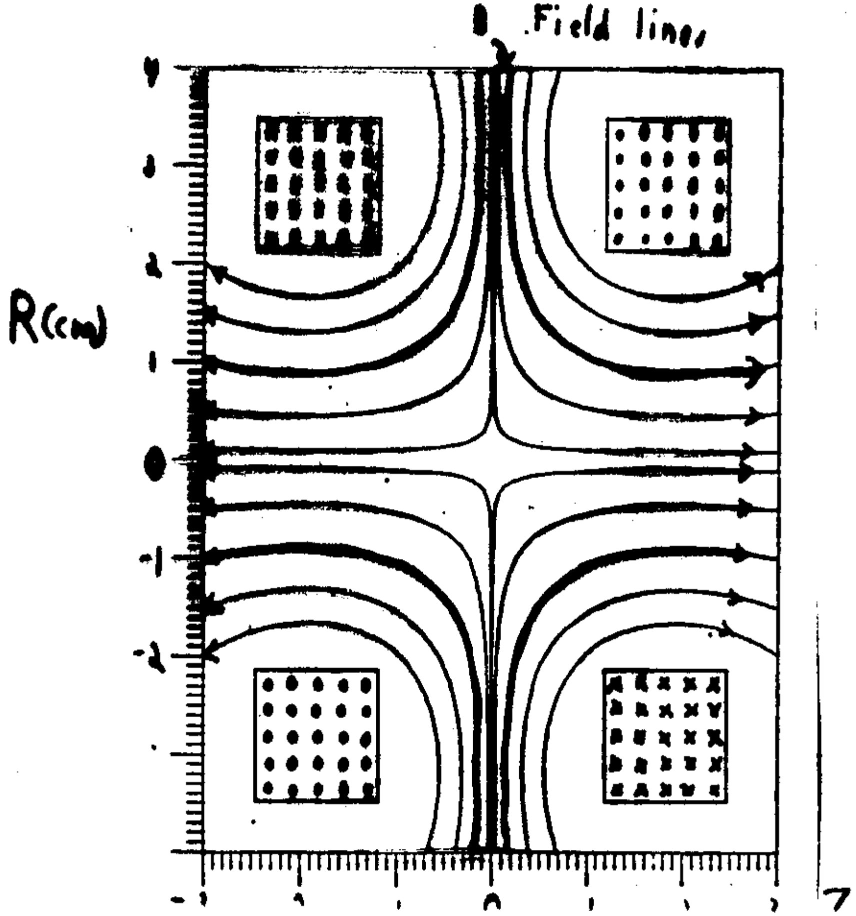
(Wing 1980)



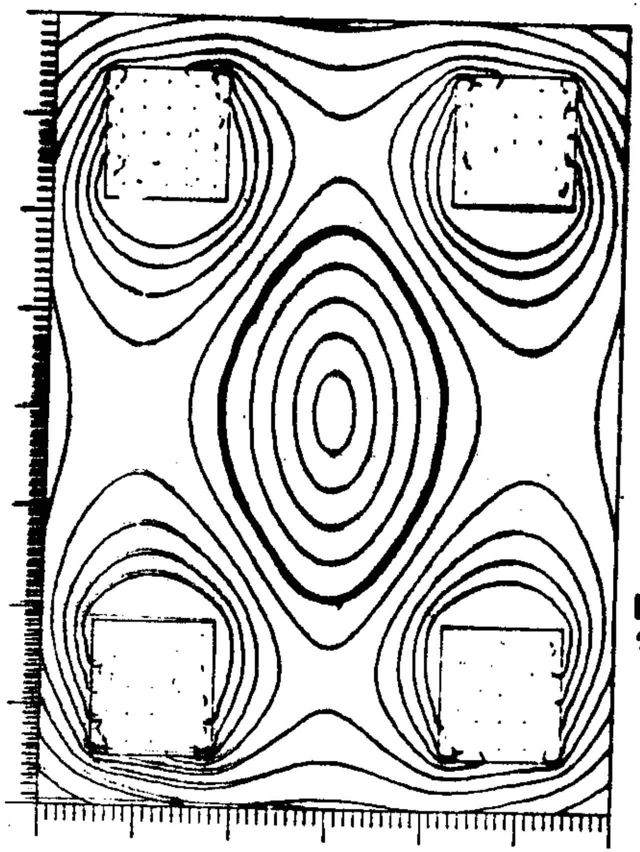


Two Opposed Coils





Adiabatic Condition
(Worst Case)



1000 Amp-turns

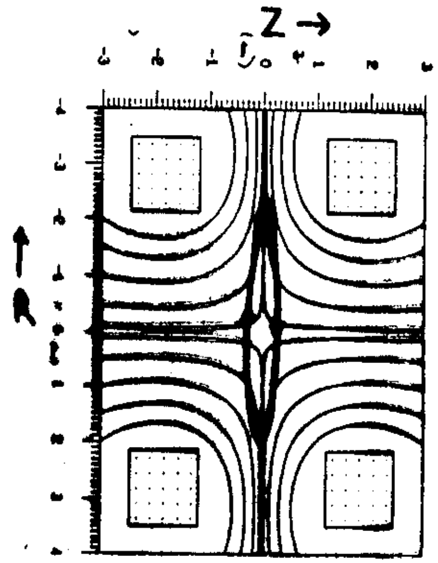
Equal field magnitudes 250 Gauss

3.5 m/sec

17 mK

$|B| \propto r$

not harmonic



Nearly Linear Orbit

V_{max} near center

T = 53 ms

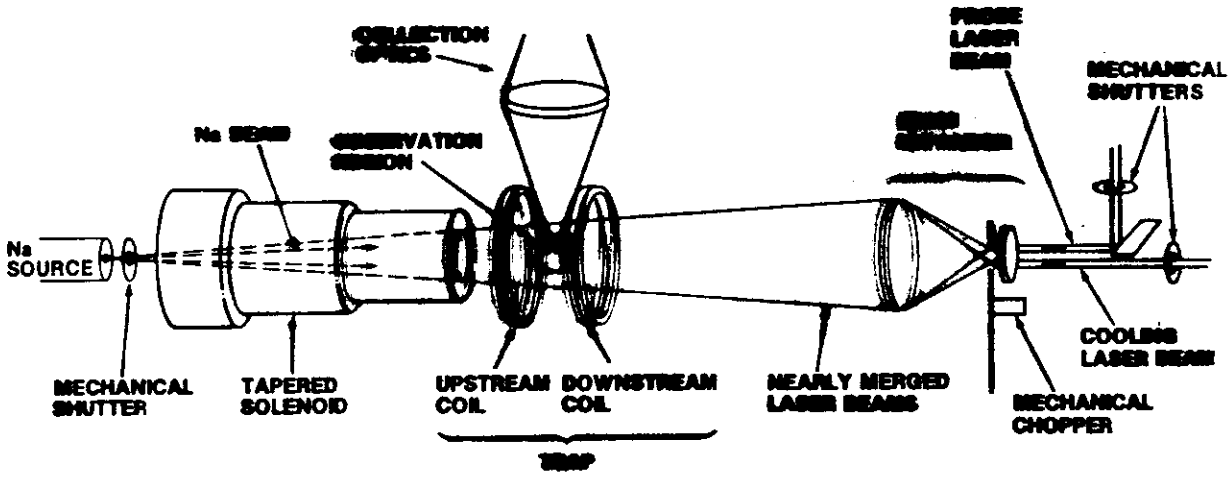
$$\omega_L \gg \omega_T$$

$$\omega_L^{min} = r_c \frac{\mu}{\hbar}\frac{dB}{dr} \gg \omega_T^{max} = \frac{v_{max}}{r_c}$$

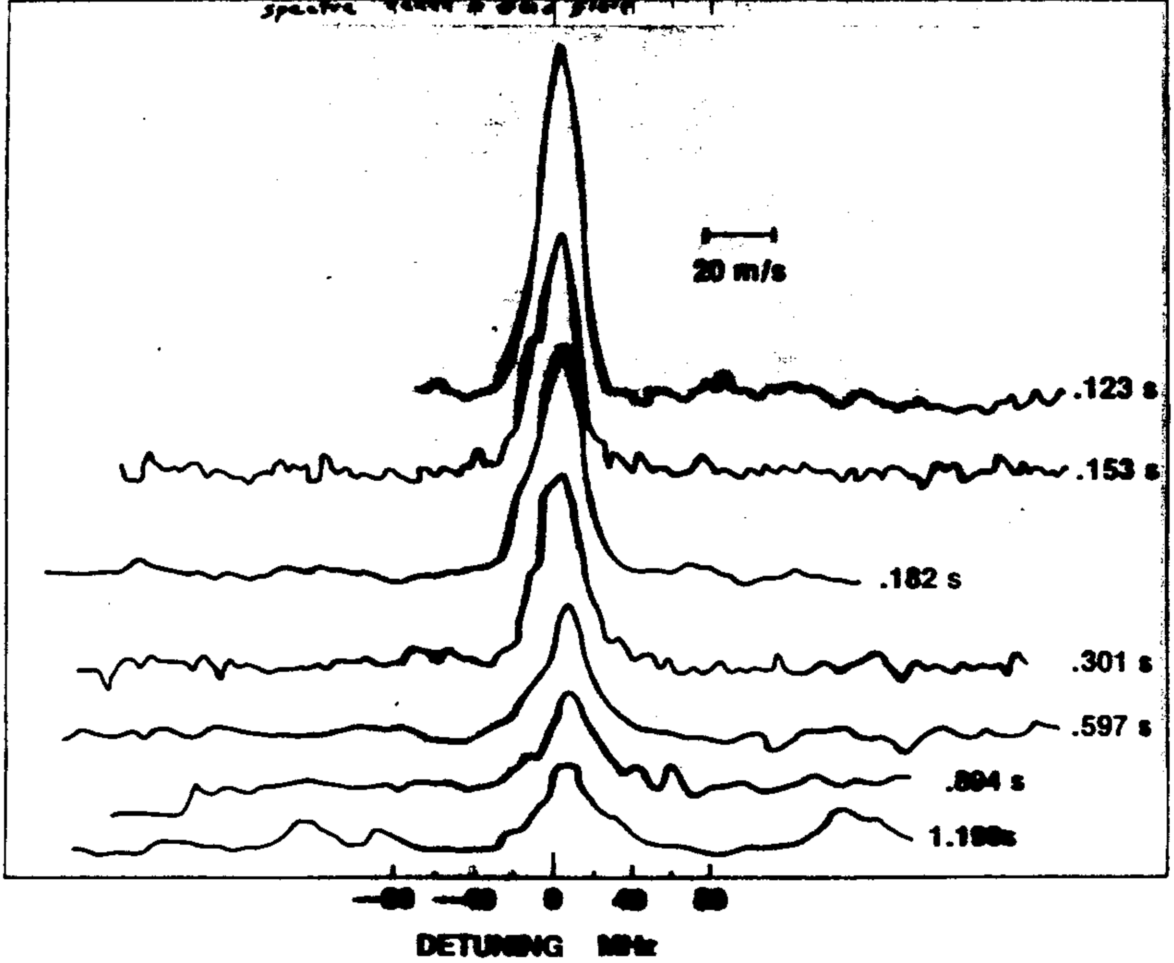
$$\Downarrow$$

$$r_c^2 \gg \frac{v_{max}\hbar}{\mu\, dB/dr}$$

$r_c \gg 6\ \mu m$ $\quad$ (10^{-10} of total vol)



spectrum of ~~atoms~~ in trap after a given time.
spectra taken in zero field



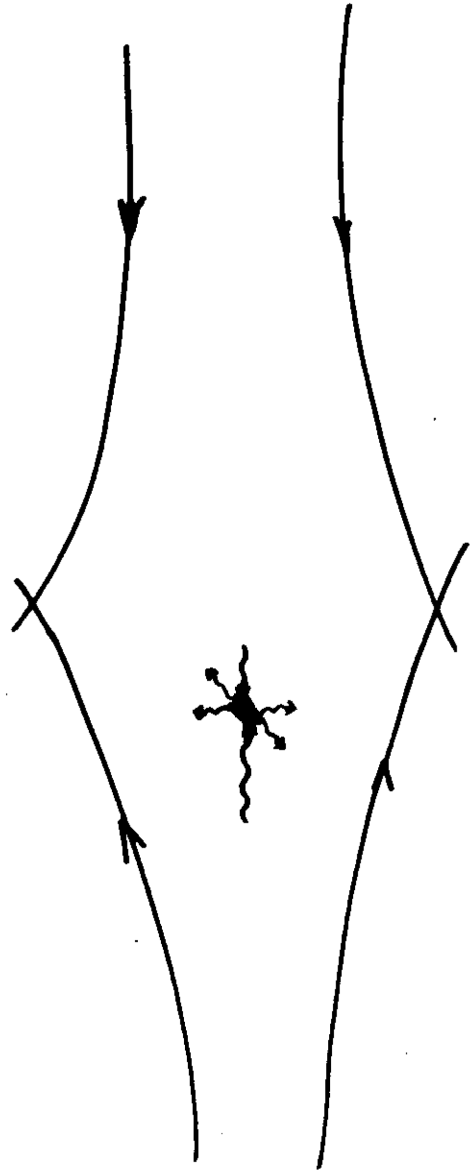
Other Magnetic Traps.

Paul :	Bonn, Grenoble	Na, n
Pritchard	MIT	Na
Kleppner + Greytak :	MIT	H
Walraven :	Amsterdam	H

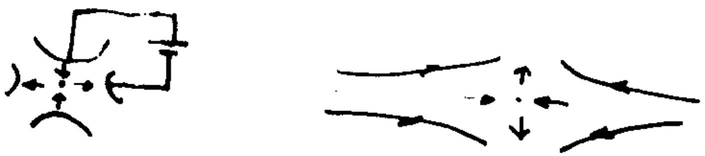
Radiation Pressure Trap

Ashkin 1978

1 - Dimensional



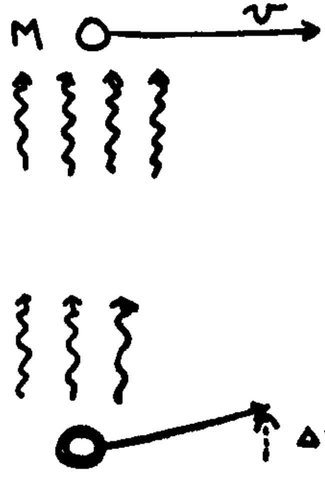
Earnshaw Theorem
(no static electric trap)



$\vec{\nabla}\cdot\vec{E} = 0$ $\vec{\nabla}\cdot\vec{S} = 0$

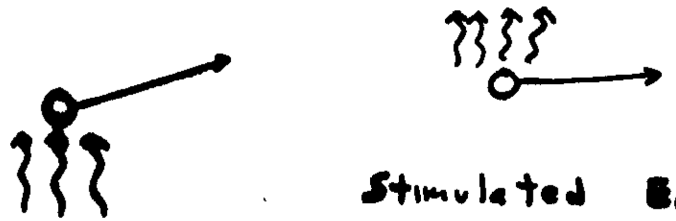
solutions: · non-static

· $\vec{F} \not\propto \vec{S}$



$\Delta v = \frac{h\nu}{Mc}$

Absorption

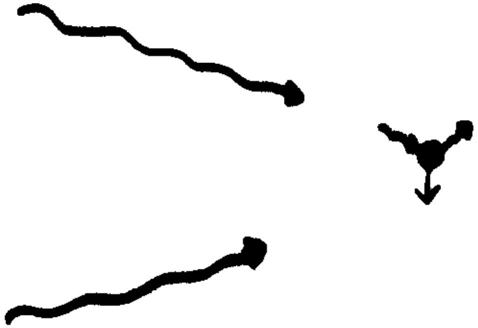


Stimulated Emission

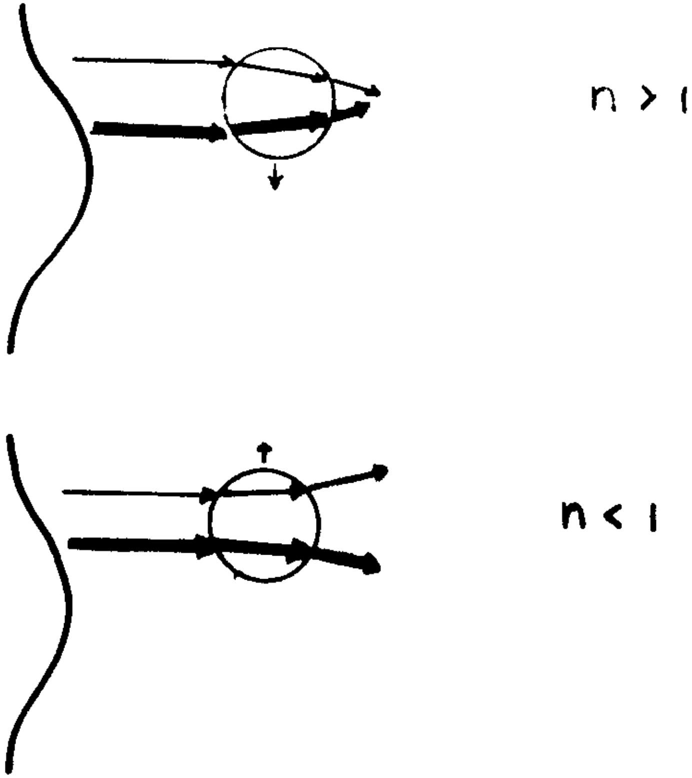
Spontaneous Emission

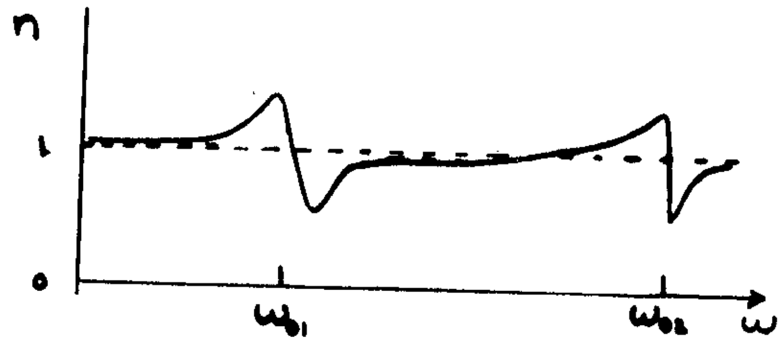
GRADIENT FORCE

Dipole Force
Gradient Force



(stimulated emission)





DIPOLE ENERGY

$$W = -\vec{\mu}\cdot\vec{E}$$

$$\vec{E} = \vec{E}_0(\vec{r})\cos(\omega t)$$

$$\vec{\mu}(t) = e\,\vec{x}(t)$$

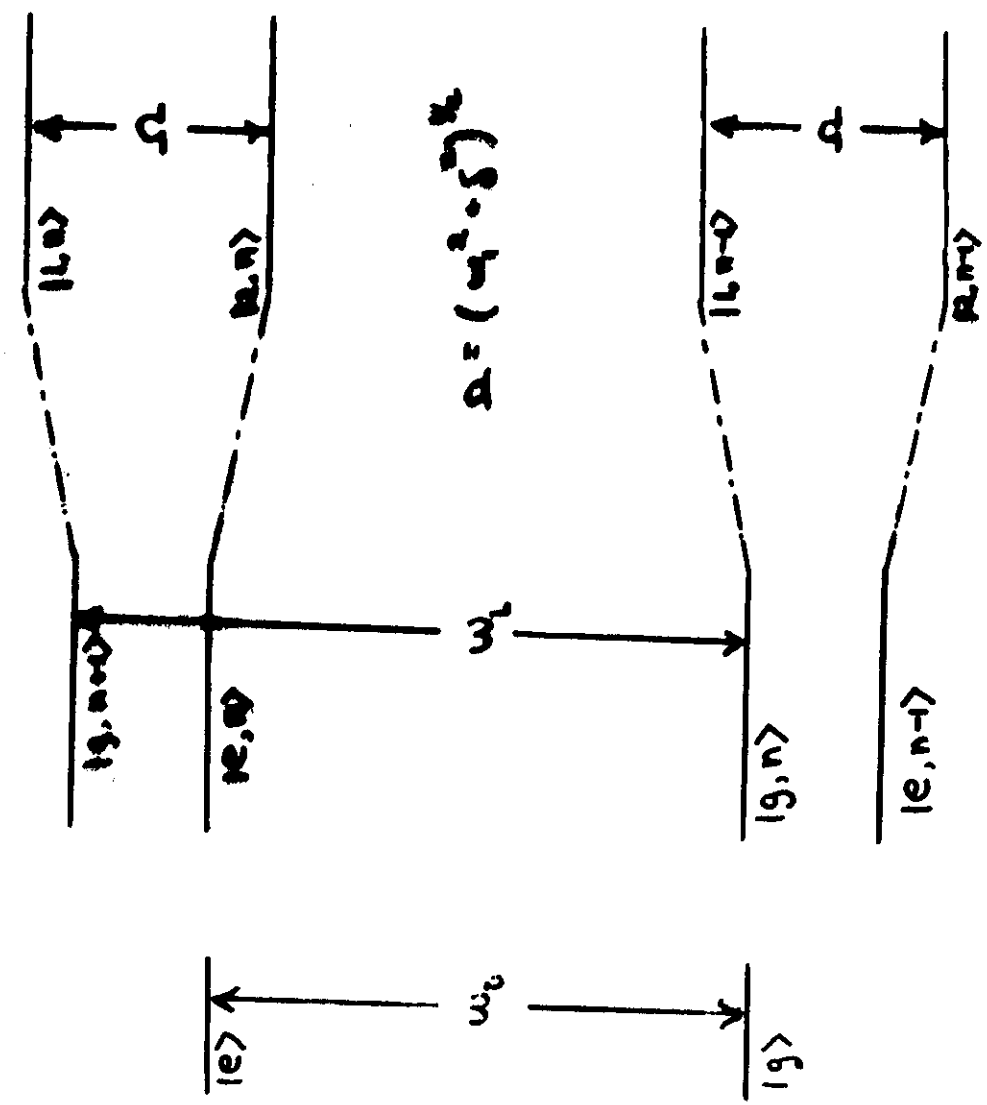
ASSUME A HARMONICALLY BOUND CHARGE:

$$\ddot{x} + \omega_0^2 x = \frac{e}{m} E_0 \cos(\omega t)$$

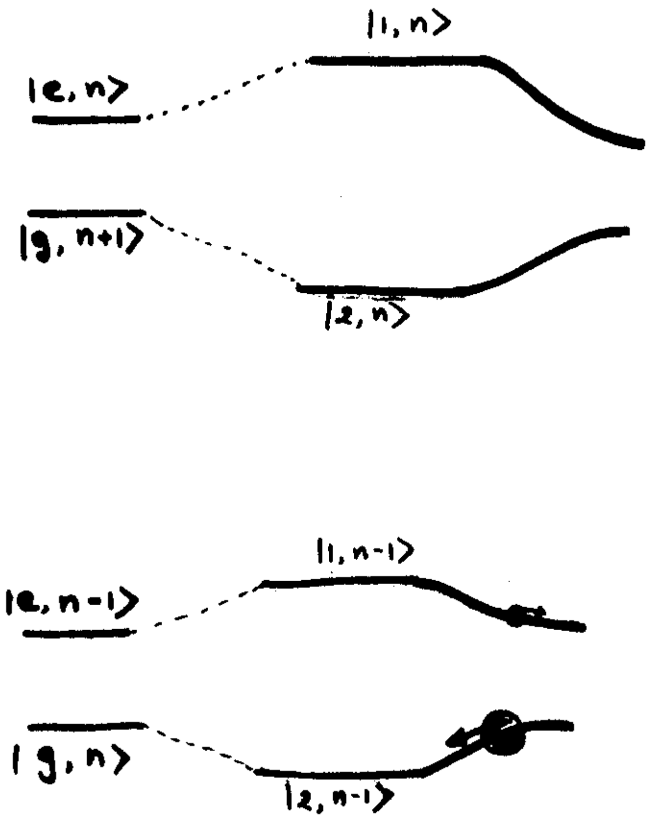
$$x(t) \propto \frac{E_0}{\omega_0^2 - \omega^2}\cos(\omega t)$$

FOR $\omega < \omega_0$: $W \sim -E_0^2$

FOR $\omega > \omega_0$: $W \sim E_0^2$



Dressed Atom Approach



(cohen-tannoudji)

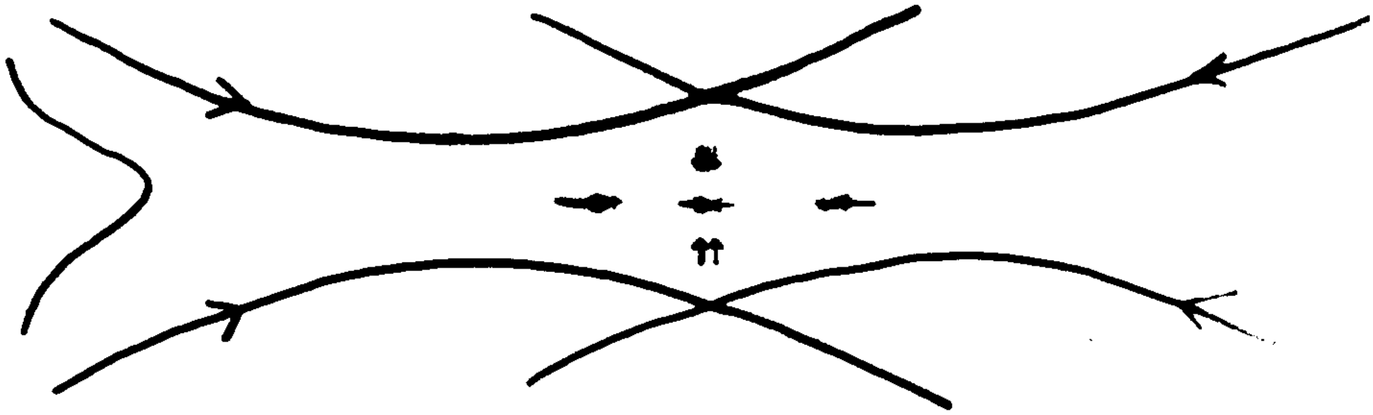
- Load From Molasses (Chu et al)

NBS: $\sim 10^{9}\ cm^{-3}$, $\sim 10^{9}$ density increase in capture volume

- Alternate Trapping Beams (Dalibard + Cohen-Tannoudji)

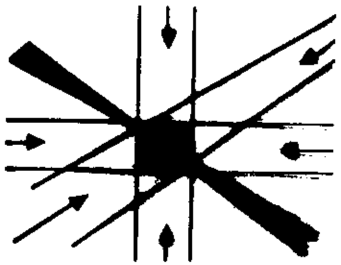
- Alternate Cooling and Trapping (Dalibard, Reynaud + Cohen-Tannoudji)

2- Focus Trap (Ashkin 1978) NBS 1987

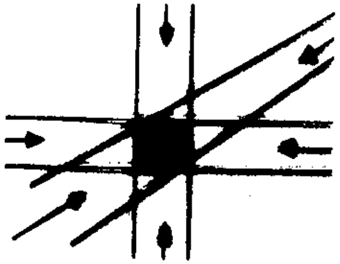


• Separate Cooling Beams (Gordon + Ashkin)

4-CYCLE HYBRID TRAP OPERATION

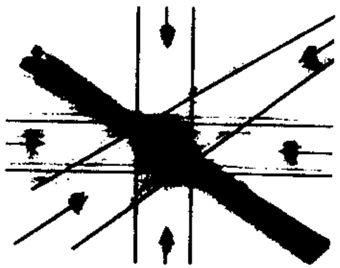


CYCLE 1
1ST TRAP BEAM

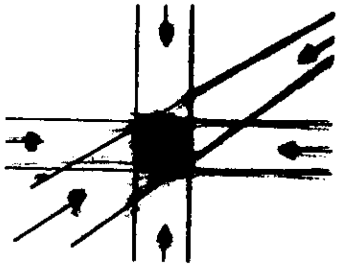


CYCLE 2
MOLASSES COOLING

EACH CYCLE: 1–10 μs

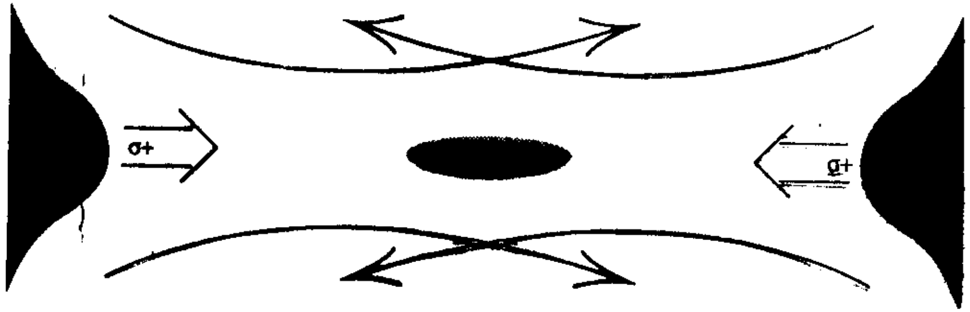


CYCLE 3
2ND TRAP BEAM



CYCLE 4
MOLASSES COOLING

Hybrid (Spontaneous and Dipole Force) Two-Focus Laser Trap



- Alternating focussed beams in molasses
  - radial confinement - dipole force
  - axial confinement - spontaneous force
  - cooling - optical molasses
- Tune trap red of resonance
- Circularly polarize to take advantage of strongest transitions

NBS hybrid laser trap