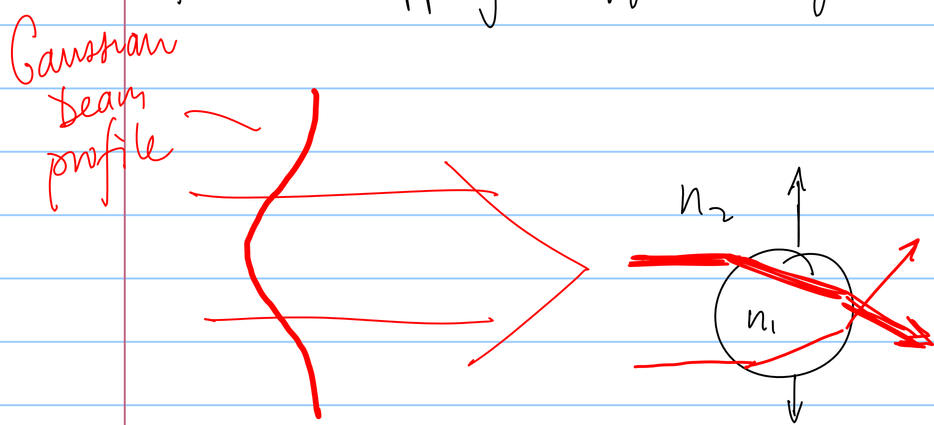
Dipole traps

Note Title 3/12/2008

Optical tweezers is a simple, classical version of laser trapping suggested by Ashkin



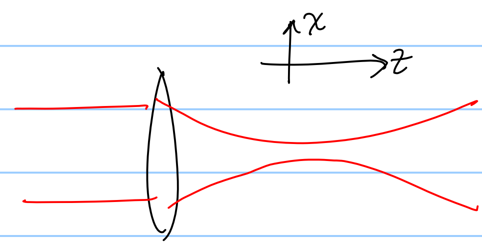
→ conservation of momentum for light and particle implies force towards regions of high intensity – just from refraction!

→ note: at it's source, this must be an effect related to what a bunch of oscillating dipoles are doing... i.e., related to the AC Stark effect

→ that's how we treat dipole forces in an atom!

AC Stark effect: $\Delta E = \hbar|\Omega|^2/\delta = \frac{\hbar\Gamma}{8}\left(\frac{\Gamma}{\delta}\right)\frac{I}{I_{sat}}$

So, we can make a trap for $\delta < 0$:



$$I = \frac{2P}{\pi W^2} e^{-2r^2/W^2}$$

P = power

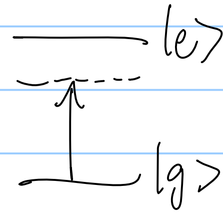
$$W = W_0\sqrt{1+\left(z/z_R\right)^2}$$

W_0: waist at focus

z_R: Rayleigh length

$\delta < 0$

"red detuned"



For atoms in the $|g\rangle$ state, an attractive potential is formed:

$$U = \frac{\hbar\Gamma}{8}\left(\frac{\Gamma}{\delta}\right)\frac{1}{I_{sat}}\frac{2P}{\pi W^2} e^{-2\frac{x^2}{W^2}}$$

This is a "dipole trap" or a "FORT"

This looks approximately harmonic in the center of the trap.

$$e^{-2r^2/w^2} \simeq 1 - \frac{2r^2}{w^2} \quad \text{for } r \ll w$$

$$\frac{1}{w^2} = \frac{1}{w_0^2}\frac{1}{1+\left(z/z_R\right)^2} \simeq \left[1 - \left(\frac{z}{z_R}\right)^2\right]\frac{1}{w_0^2} \quad \text{for } z \ll z_R$$

So, $$e^{-2r^2/w^2} \simeq 1 - 2r^2\left[1 - \left(z/z_R\right)^2\right]\frac{1}{w_0^2} \simeq 1 - \frac{2r^2}{w_0^2}$$

and $$\frac{2P}{\pi w^2} e^{-2r^2/w^2} \simeq \frac{2P}{\pi w_0^2}\left[1 - \left(z/z_R\right)^2\right]\left(1 - \frac{2r^2}{w_0^2}\right)$$

$$\simeq \frac{2P}{\pi w_0^2}\left[1 - \frac{2r^2}{w_0^2} - \left(z/z_R\right)^2\right]$$

Note $z_R = \frac{\pi w_0^2}{\lambda}$

So, $$U = -U_0\left[1 - \frac{2r^2}{w_0^2} - \left(z/z_R\right)^2\right]$$

where

$$U_0 = \frac{2P}{\pi w_0^2}\frac{\hbar\Gamma}{8\, I_{sat}}\frac{\Gamma}{|\delta|}$$

harmonic oscillator frequencies:

$$\frac{1}{2} m \omega_r^2 = U_0 \frac{2r^2}{W_0^2}$$

$$\omega_r = \sqrt{\frac{4U_0}{m w_0^2}}$$ ← shrink w_0, increase power to make a stiffer trap

$$\omega_z = \sqrt{\frac{U_0}{m z_R^2}}$$

throw in some numbers:

- for ^{87}Rb, $S_{1/2} \rightarrow P_{3/2}$,
- let's say $\lambda = 850$ nm $\quad \omega = c\frac{2\pi}{\lambda}$
- and $I_0 = \frac{2P}{\pi W_0^2}$ where P = incident power

$$W_0 = 10\,\mu m, \; P = 100\text{ mW}$$

$\omega_r = 2\pi \cdot 1.2$ kHz

$\omega_z = 2\pi \cdot 16$ Hz

$V_0 = 15\,\mu K \cdot k_B$

Note: must detune sufficiently to avoid heating →

$R \propto 1/\delta^2 \quad U \propto 1/\delta$

→ you even do better than this b/c counter-rotating term contributes to U at large δ

Note:

blue detuned dipole traps (in alternate geometries) are also useful

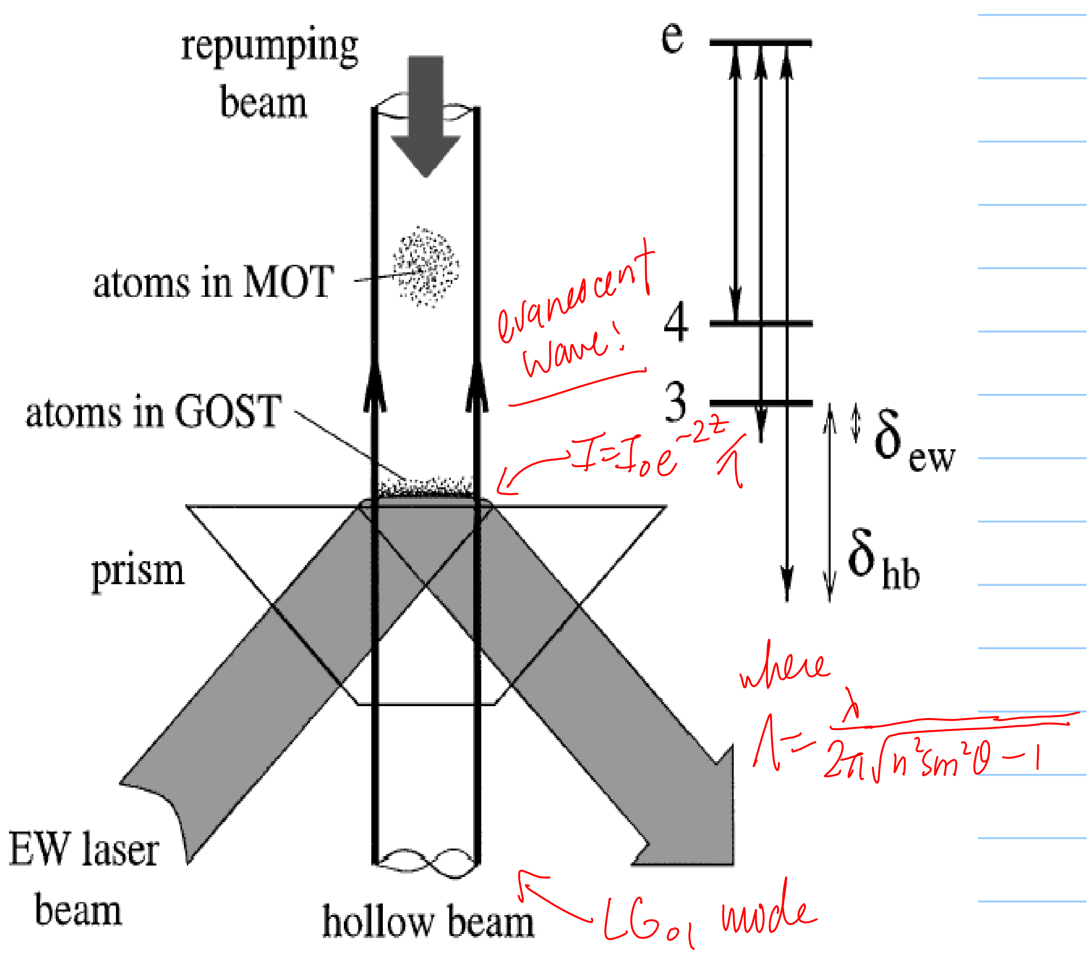
VOLUME 79, NUMBER 12 PHYSICAL REVIEW LETTERS 22 SEPTEMBER 1997

Surface Trap for Cs atoms based on Evanescent-Wave Cooling

Yu. B. Ovchinnikov, I. Manek, and R. Grimm
Max-Planck-Institut für Kernphysik, 69029 Heidelberg, Germany
(Received 20 June 1997)

We demonstrate a gravito-optical surface trap for Cs atoms which exploits cooling in an evanescent light wave. About 10^5 atoms were cooled down to 3 μK and formed a sample with a mean height of ~20 μm above the surface of a dielectric prism. The trap does not use a magnetic field and leads to very small atomic level perturbations. The excited-state population of the stored atoms is ~1.5×10^{-6} and collisional losses are strongly suppressed. [S0031-9007(97)04024-6]

PACS numbers: 32.80.Pj, 42.50.Vk



[redacted]

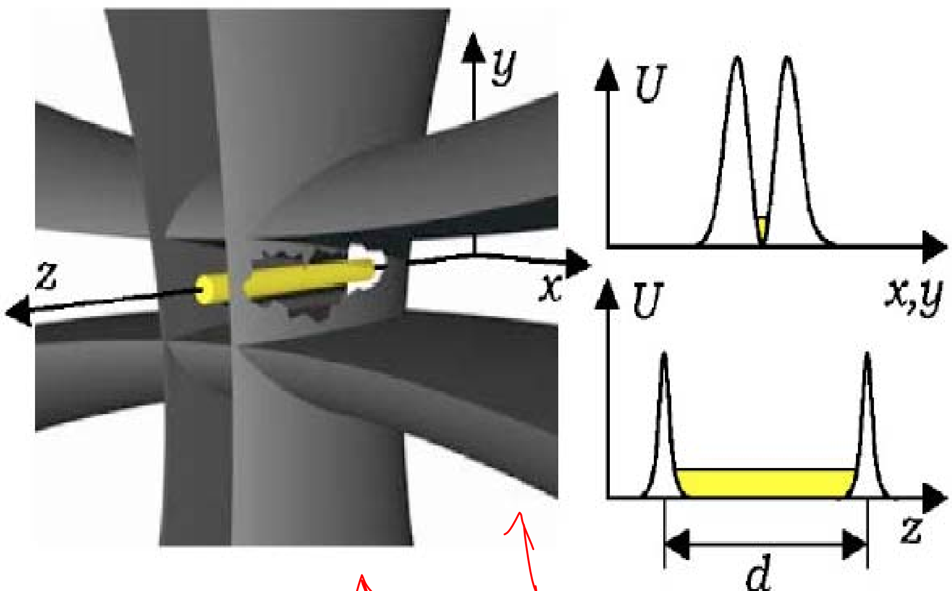
PHYSICAL REVIEW A **71**, 041604(R) (2005)

Bose-Einstein condensate in a box

T. P. Meyrath, F. Schreck,* J. L. Hanssen,† C.-S. Chuu, and M. G. Raizen
Center for Nonlinear Dynamics and Department of Physics, The University of Texas at Austin, Austin, Texas 78712-1081, USA
(Received 8 December 2004; published 29 April 2005)

Bose-Einstein condensates have been produced in an optical box trap. This optical trap type has strong confinement in two directions comparable to that which is possible in an optical lattice, yet produces individual condensates rather than the thousands typical of a lattice. The box trap is integrated with single-atom detection capability, paving the way for studies of quantum atom statistics.

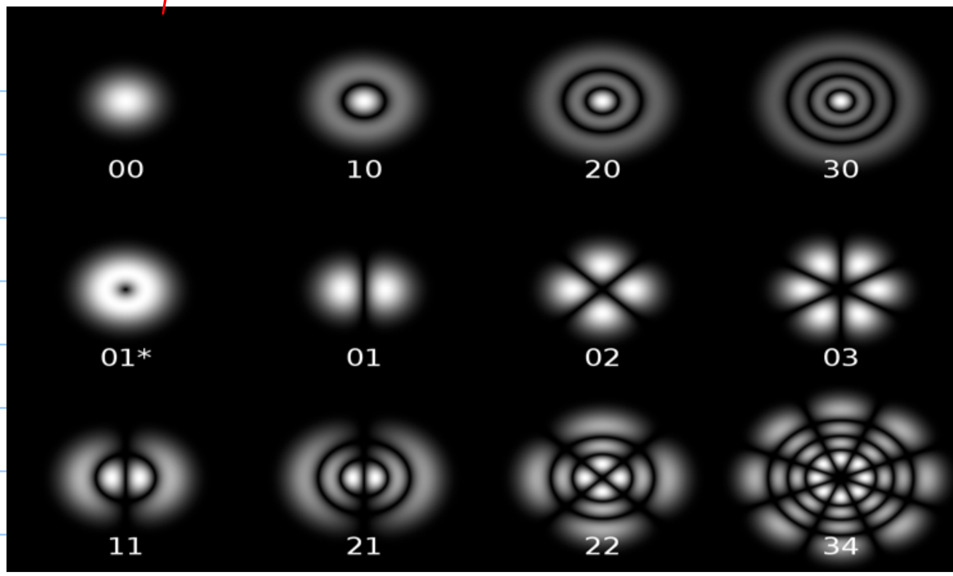
DOI: 10.1103/PhysRevA.71.041604 PACS number(s): 03.75.−b, 32.80.Pj, 39.25.+k



TEM$_{10}$ H/G mode

TEM$_{01}$ H/G mode

Laguerre-Gaussian Modes



Hermite-Gaussian modes