Magneto-Optical Trap in the Limit of Very Large Number of Atoms

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OUTLINE

1. Motivation and Objectif;
2. Description of differents MOT regimes;
3. Model for MOT size;
4. Prespectives:
    - Compression;
    - Multiple scattering in a dense MOT.

INTRODUCTION

IN THE PAST IN NICE:

Experiments with Optical thick cloud ($b \equiv n\,\sigma\,L \gg 1$)

but Dilute

$$\Downarrow$$

$$\boxed{k \cdot \ell \gg 1}$$

($\triangleq$ at resonance $d_{at-at} \gg \lambda$)

GOAL:

Multiple scattering with Optical thick cloud

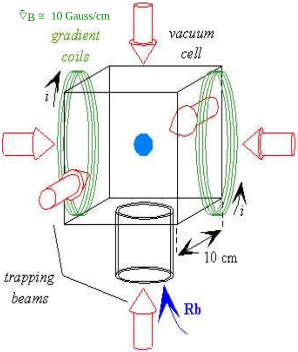
plus Dense medium

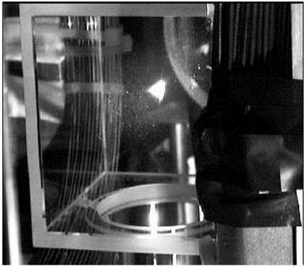
$$\Downarrow$$

$$\boxed{k \cdot \ell \sim 1}$$

($\triangleq$ at resonance $d_{at-at} \sim \lambda$)

PREPARATION OF ^{85}Rb ATOMIC SAMPLE





- Trap Light:
  - Six independent beams;
  - Line D_2 (F = 3 $\longrightarrow$ F'=4);
  - $\delta = -3\Gamma$;
- Repumping Light:
  - Line D_2 (F=2 $\longrightarrow$ F'=3);
  - Control of total Number of atoms;

$$\boxed{N_{at} \simeq 10^{10}, n \simeq 10^{10}\, cm^{-3}, v \sim 0.1\, m/sec}$$

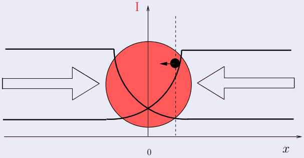
Wieman Model and MOT Size

One Atom

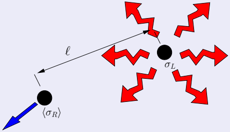
$$\boxed{F = -\kappa x - \gamma v + \delta F} \Rightarrow \boxed{\frac{1}{2}k_B T = \frac{1}{2}\kappa x^2}$$

Size Indep.of N_{at}

Shadow Effect:



Binary Interaction:



$\Rightarrow$

$$\boxed{\vec{\nabla}\cdot\vec{F} \propto n(\vec{r})\cdot(\langle\sigma_R\rangle - \sigma_L) - 3\cdot\kappa}$$

$n\cdot\sigma_L$ and κ $\rightarrow$ COMPRESSION

$n\cdot\langle\sigma_R\rangle$ $\rightarrow$ REPULSION

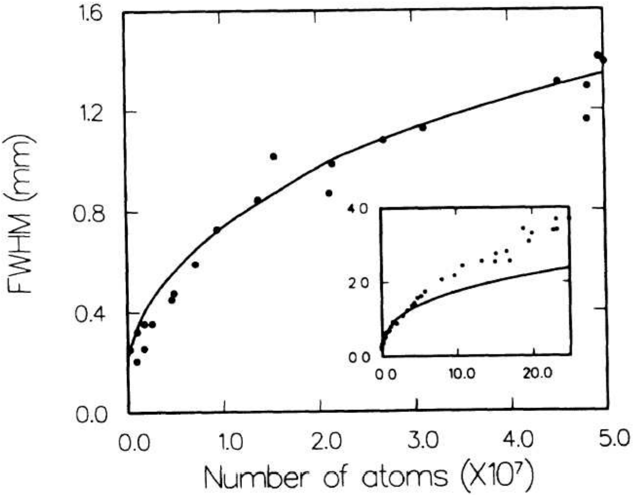
$$\Downarrow$$

$$\boxed{n_{cw} = \frac{\kappa}{\Gamma\frac{I}{I_{sat}}(\langle\sigma_R\rangle - \sigma_L)}}$$

$$\downarrow$$

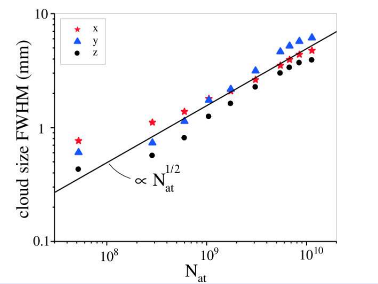
$$\text{Size} \propto N_{at}^{1/3}$$

LIMITS OF WIEMAN MODEL



[*T.Walker, PRL et al., 64, 408 (1990)]*

OUR EXPERIMENTAL RESULTS

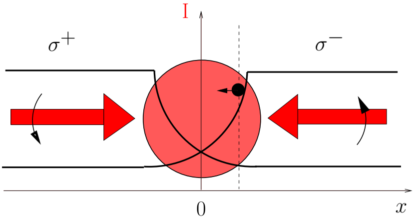


$$N_{at} \lesssim 10^8 \rightarrow \quad L \propto N_{at}^{1/3} \Rightarrow \quad n = const$$

$$N_{at} \gtrsim 10^8 \rightarrow \quad L \propto N_{at}^{1/2} \Rightarrow \quad b(\delta) = const$$

$$\begin{cases} b(\delta = -3\,\Gamma) \simeq 1 \\ b(0) \simeq 40 \end{cases}$$

MODEL



HOMOGENEOUS ATOMIC DENSITY: $n = \frac{N_{at}}{L^3}$, *with* $\eta = \frac{\langle \sigma_R \rangle}{\sigma_L}$ *and* $\ell = \frac{1}{n\,\sigma}$

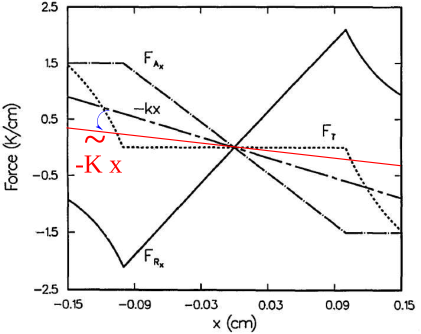
$$F(x) = \frac{\hbar k \Gamma}{2} \frac{I}{I_{sat}} \frac{e^{-\frac{(x+L/2)}{\ell}}}{1 + \frac{4(\delta - \mu x)^2}{\Gamma^2}} - \frac{\hbar k \Gamma}{2} \frac{I}{I_{sat}} \frac{e^{\frac{(x-L/2)}{\ell}}}{1 + \frac{4(\delta + \mu x)^2}{\Gamma^2}} +$$

$$+\eta \frac{\hbar k \Gamma}{2} \frac{I}{I_{sat}} \frac{1}{1+4\,(\frac{\delta}{\Gamma})^2} \frac{(1-e^{-b})}{L/2} x$$

Multiple Scattering Term.

LINEAR APPROXIMATION

- Approximation of Wieman Model:
  1. Linear in x;
  2. $b \ll 1$;



FIRST ORDER IN x AND b:

$$F(x) = \{\mu \cdot (1 - b/2)[..] + Shadow\ Effect + \eta[..]\}x$$

Correction of spring constant

SIZE PREDICTION

AT EQUILIBRIUM: $F(x) = 0, \forall\, x$

$$\underbrace{\frac{N_{at}\sigma_0}{8\,\delta\mu/\Gamma^2}(1-\eta)}_{A} = L^3 - \underbrace{\frac{N_{at}\sigma_0 L}{2(1+4\,\frac{\delta^2}{\Gamma^2})}}_{B}$$

$$\mathit{If}\ A > B \ \Rightarrow\ L \ \propto\ N_{at}^{1/3} \ \longrightarrow\ \mathit{density}\ n = \mathit{const};$$

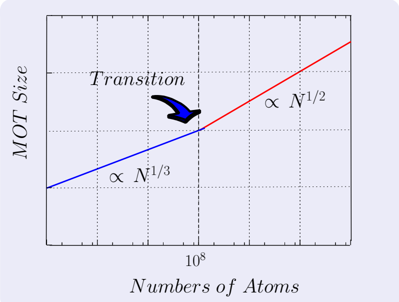
$$\mathit{If}\ A < B \ \Rightarrow\ L \ \propto\ N_{at}^{1/2} \longrightarrow\ \mathit{optical\ thickness}\ b = \mathit{const};$$

$$A = B$$

$$\Downarrow$$

$$\boxed{\delta \cdot (\eta - 1) \sim \mu \cdot L}$$

STUDY OF TRANSITION CONDITION



A = B

$$\delta \cdot \underbrace{(\eta - 1)}_{\substack{\downarrow \\ 0 \\ \text{When} \\ I \longrightarrow 0}} \sim \overbrace{\mu}^{\vec{\nabla} B} \cdot L$$

Short term objectif:

$$\boxed{\text{Experimental study as functions of Parameters } (\delta,\ I,\ \vec{\nabla} B)}$$

SUMMARY

- New scaling law for MOT size when N_{at} above 10^8;
- Qualitatively understanding of $L(N_{at})$;
- Outlook
  - Now: $k \cdot \ell \sim 1000$;
  - Experimental validation of the model;
  - Reach very high spatial densities;
  - GOAL: $k \cdot \ell \sim 1$