In the previous lecture, we learned how to make use of a laser to cool atoms. However, the atoms will not be trapped.

Now, how to make use of radiation pressure to trap atoms.

Confirmation for optical molasses:

Atoms experience a radiation force $\vec{F} = \frac{1}{2} \alpha \vec{E}^2$, but no trapping force, which would be $\vec{F}_T = \alpha \vec{E}^2$. 

\( \alpha = \)
(2) Normal force at the point of contact of the two objects.

\[ N = \sqrt{1 + \frac{1}{4}} \]

Distance equation:

\[ d = \sqrt{1 + \frac{1}{4}} \]

Resultant force:

\[ F = \sqrt{1 + \frac{1}{4}} \]

Equation for normal force:

\[ N = \sqrt{1 + \frac{1}{4}} \]

Normal force at the point of contact of the two objects.
Consider a walkers only atom for the simplest possible model of a
where the ground state of the atom to be a

\[ y = 0 \]

\[ y = 1 \]

Consider now the energy structure of the

atom in an external unperturbed field as above

\[ y = 1 \]

\[ y = 0 \]

\[ y = -1 \]

\[ y = -1 \]

Now set the propagation as above

\[ z = 1 \]

\[ z = 0 \]

\[ z = -1 \]

\[ z = -1 \]
Consider how an allow ball moving along a position with constant velocity in the direction of the optical force.

In addition, we observe that the velocity decreases as the position increases.

Reason. 2. Reflex reduces the velocity.

Therefore, $y = 0$, $w_j = 0$ and no force is applied.

Note that the force is not dependent on the position.

\[
\begin{align*}
\frac{\partial}{\partial x} \left[ \frac{\partial}{\partial x} \right] \left[ (u - \frac{\partial}{\partial x}) \right] - \left( (u - \frac{\partial}{\partial x}) \right) - \left( (u - \frac{\partial}{\partial x}) \right) \\
\end{align*}
\]
Damped harmonic oscillator:

\[
\sqrt{\frac{g}{2}} = \sqrt{\frac{100}{2}} = 5\text{ m/s}
\]

\[
\text{Cohere velocity:} \quad \omega_n = 100\text{ rad/s}
\]

\[
5\mu \text{ s} = L_0 = \frac{100}{\omega_{\text{max}}}
\]

\[
\frac{5}{\sqrt{5}} \approx 3.67
\]
1988: W. Phillips et al.

The Doppler Limit

No Larmor Cutoff below

N.B. Sub-Doppler Larmor Cutoff

PRL 60 (1988)

Experiments:

Sodium atoms in an optical molasses

Sodium condensation because of 3D motion

\[ \frac{1}{2} = \frac{kT}{2} \]

\[ \frac{1}{2} \frac{181}{216} + \frac{1}{2} \frac{181}{216} \]

\[ s = \frac{1}{2} \]

\[ T \]

\[ 181 \]

\[ 1982: \text{Chu, Phillips, Cohen-Tannoudji} \]

Nobel Prize:
A.6.A. Sisyphus Cooling

\[ g = \frac{3}{2} \]

\[ j = \frac{1}{2} \]

\[ j \leq \frac{1}{2} \]

\[ + \frac{1}{2} \]

\[ - \frac{1}{2} \]

\[ - \frac{1}{2} \]

K.2. Jalesi atoms

2. \( P_{31/2} \)

2. \( P_{11/2} \)

2. \( S_{1/2} \)

D2-eu.
\[ \int \left( \frac{\hbar}{m} v \cos \theta + \frac{\hbar}{m} \right) + E_0 \sin \left( \frac{\hbar}{m} v \cos \theta - \frac{\hbar}{m} \right) \, dt \]
Consequences

(1) Optical pumping and spatially confining

The atoms have to be slow enough to be pumped into a specific level and certain positions stable enough to avoid losses.

- Population accumulates in \( w_y = -1 \)
- Population accumulates in \( w_y = +1 \)
\[
\left( (y(2)^{\frac{2}{3}} + V + x)^{\frac{2}{3}} \right) \Delta = -\frac{2}{3} \frac{\partial}{\partial \Delta} \left( \frac{2}{3} V + x \right)
\]
\( f_3 (n^2) \) is a centrosymmetric face with an associated potential.

\[ U_3 (n^2) = \frac{k \Phi}{2} \ln \left[ 1 + s(n^2) \right] \]

The sign of the potential depends on the sign of \( s \):

- Red absorption (\( s < 0 \))
  - Atoms will be attracted to regions of higher index
  - \( \rightarrow \) dipole repulsion

- Blue absorption (\( s > 0 \))
  - \( \rightarrow \) repulsion from regions of high index
  - \( \rightarrow \) e.g., atom mirror

For \( |s| \ll n \) and \( s < n \) (weak index)

\[ \ln \left[ 1 + s \right] \approx s \approx \frac{\Omega n^2}{2} \]

\[ U_3 \approx \frac{k \Omega n^2}{4} \frac{1}{\Phi} \]

Describe the dipole potential of the interaction.
Now, describe the atom-light interaction in a dressed state picture.

Dipole force between two potential leads to a shift of energy eigenvalues.

$\Delta E = \frac{1}{2} g \bar{\alpha} |\bar{\alpha}|$ for the dressed state system.

Why are we not discussing the issue of spontaneity or describing a ground state with spontaneously created particles in a dipole field?

Consider:

$\frac{1}{2} g \bar{\alpha} |\bar{\alpha}| = \frac{1}{2} \left( \frac{1}{\sqrt{12}} \right)^2 (1 \cdot 12) = \frac{1}{12}$

$\bar{\alpha}$ spacelike

Note that the unit vectors are not normalized.

$\bar{\alpha} = 1/\sqrt{3}$

$\alpha = 1/\sqrt{12}$

$\beta = 1/\sqrt{2}$
\[ \frac{\sqrt{g}}{L} \]

\[ g \approx \frac{8}{L} \]

\[ \Rightarrow \quad g \approx \frac{1}{L} \]

\[ \frac{\gamma}{5} \quad \frac{\gamma}{5} \quad \frac{\gamma}{5} \]

\[ \frac{g}{\sqrt{2}} \quad \frac{g}{\sqrt{2}} \quad \frac{g}{\sqrt{2}} \]

\[ \frac{2\gamma + p}{2\gamma + p} = \frac{\gamma}{\sqrt{2}} \]

\[ \frac{\gamma}{\sqrt{2}} \quad \frac{\gamma}{\sqrt{2}} \quad \frac{\gamma}{\sqrt{2}} \]

\[ \pm = -\sqrt{\frac{g}{\gamma}} \]

\[ \Delta \in H \quad g \equiv \quad \pm = \Delta \in H \]

\[ \Delta \in H \quad g \equiv \quad \pm = \Delta \in H \]

\[ \pm = \Delta \in H \quad g \equiv \quad \pm = \Delta \in H \]

\[ \pm = \Delta \in H \quad g \equiv \quad \pm = \Delta \in H \]

\[ \frac{1}{\gamma} \sim \frac{1}{\gamma} \]

\[ \frac{1}{\gamma} \sim \frac{1}{\gamma} \]

\[ \frac{1}{\gamma} \sim \frac{1}{\gamma} \]

\[ \frac{1}{\gamma} \sim \frac{1}{\gamma} \]
A molecule's angular momentum (\(\Omega\)) is quantized, leading to a discrete angular momentum spectrum.

\[ \Omega = \frac{n\hbar}{2\pi} \]

Some other key points:

- The maximum angular momentum is related to the orbital angular momentum.
- The relationship between the orbital angular momentum and the total angular momentum is given by the projection quantum number (\(m\)).

\[ m = \pm L \]

\[ L = \sqrt{n^2 - m^2} \]
$N_a \sim E_r \sim 2.4 \mu K$

$E_x = \frac{2H}{1.24}$

$\frac{E_3}{E_x} = \frac{1}{7}$

The sticks will all be in equilibrium.

Gooby kiwi for cuff-jumper cocky.