Physics 4062/5062 – Lecture 12- Optical Dipole Force –Discussion based on OBEs

$$x(t) = x_{12}\left(U\cos(\omega t) - V\sin(\omega t)\right) \qquad \textbf{(224)} \text{ - Similar to (234)}$$

In the OBE model x_{12} represents the expectation value

Use (224) and (257)

$$\langle F_z \rangle = \left(\frac{1}{2}\right) q x_{12}\left[U\frac{\partial E_o}{\partial z} - VkE_o\right] = F_{dipole} + F_{abs} \qquad \textbf{(262)} \text{ - Similar to (259)}$$

Use steady state OBE solutions given by (249) in (262) and the definition of the Rabi frequency $\Omega = \frac{q x_{12} E_0}{\hbar}$ to find expressions for the optical dipole force and the absorption force

$$F_{dipole} = \left(\frac{-\hbar\Delta}{2}\right)\left[\frac{\Omega}{\Delta^2 + \left(\frac{\Omega^2}{2}\right) + \left(\frac{\Gamma^2}{4}\right)}\right]\left[\frac{\partial\Omega}{\partial z}\right] \quad \mathbf{(263)}$$

$$F_{abs} = \hbar k\left(\frac{\Gamma}{2}\right)\left[\frac{\Omega^2/2}{\Delta^2 + \left(\frac{\Omega^2}{2}\right) + \left(\frac{\Gamma^2}{4}\right)}\right]$$

F_{abs} is the same as equation (254) derived starting from $R = \Gamma\rho_{22}$

Remarks: Equation (263) predicts same frequency dependence as result of classical model given by equations (260) and (261). However, in the denominator, Γ is replaced by

$$\Gamma[1+2(\Omega/\Gamma)^2]^{1/2} \qquad \text{(Power Broadening)}$$

$F_{dipole} = 0$ when $\Delta = 0$ (just like the classical model)

Far Detuned Limit

For $|\Delta| \gg \Gamma$, $\Delta \gg \Omega$

$$F_{dipole} \sim -\left(\frac{\partial}{\partial z}\right)\left(\frac{\hbar\Omega^2}{4\Delta}\right) \qquad \mathbf{(264A)}$$

$\frac{\Omega^2}{4\Delta}$ (light shift parameter) is related to the AC Stark shift in polarization gradient cooling. Since

$$F_{dipole} = -\nabla(U_{dipole})$$

$$U_{dipole} \sim \frac{\hbar\Omega^2}{4\Delta} \sim \left(\frac{\hbar\Gamma}{8}\right)\left(\frac{\Gamma}{\Delta}\right)\left(\frac{I}{I_s}\right) \quad \textbf{(264B)}$$

Remarks:

For Δ positive, $U = U_{max}$ when I is highest

So atoms are repelled from high intensity!
For Δ negative, atoms are attracted to high intensity!

Discuss implications for differing beam profiles

Scaling laws in the far detuned limit:

$$R_{scatt} = \left(\frac{\Gamma}{2}\right)\left[\frac{\frac{\Omega^2}{2}}{\Delta^2+\left(\frac{\Omega^2}{2}\right)+\left(\frac{\Gamma^2}{4}\right)}\right] \quad \textbf{(252)}$$

For |Δ| >> Γ and | Δ| >> Ω

$$R_{scatt} \sim \left(\frac{\Gamma}{8}\right)\left(\frac{\Gamma^2}{\Delta^2}\right)\left(\frac{I}{I_s}\right) \quad \textbf{(265)}$$

$$R_{scatt} \sim \frac{I}{\Delta^2}$$

Whereas trap depth in equation (264) $U_{dip} \sim \frac{I}{\Delta}$

Best Conditions for ODF Trap (also called FORT → far off resonance trap)

High intensity (at focus),
Far off resonance

These conditions ensure low scattering rate and reasonably high well depth

Example:

FORT with λ = 1 μm for trapping Rb atoms.

Note that λ_0~ 780 nm. So Δ is negative

Assume P = 1 W and that the diameter of the focal spot is ~ 20 μm

Find the trap depth in units of temperature- discover that it sufficiently large to trap atoms initially loaded into a MOT!

Find the photon scattering rate R_{scatt} – discover that it is of order 1/s !