Dipole trap for ^{87}Rb atoms using lasers of different wavelength

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The parity of atomic wave functions prevents neutral atoms from having permanent electric-dipole moment. Electric-dipole moment is induced in an atom when exposed to strong light, the electric field of the light. Hence the optical trapping of neutral atoms relies on the induced dipole moment. Here we present the calculated numerical values of the detuning, potential depth, minimum laser power required to trap ^{87}Rb (D_2 line) atoms using lasers of wavelength 1064 nm, 850 nm, 820 nm and 800 nm and beam waists 50μm, 100μm and 200μm.

INTRODUCTION

Trapping and storage of charged and neutral particles have laid pathways for advancement in physics [?]. Neutral atoms are trapped on the basis of magnetic and optical interactions. Magnetic traps represent ideal conservative traps and arise from the state-dependent force on the permanent magnetic dipole moments in inhomogeneous field, restricting the experiments to only few special case. Optical dipole traps [?], which is much weaker than other trapping mechanism rely on the electric dipole interaction with far-detuned light. Under appropriate conditions, the dipole trapping mechanism is independent of the particular sub-level of the electronic ground-state. The internal ground state can thus be fully exploited for experiments which is not possible in magnetic trapping mechanism.

FREQUENCY-DETUNING AND POTENTIAL DEPTH FOR ^{87}Rb ATOMS

Effective laser detuning Δ for alkali's can be calculated using,

$$\frac{1}{\Delta} = \left(\frac{1}{\Delta_1} + \frac{2}{\Delta_2}\right) \tag{1}$$

where Δ_i is detuning from D_i line.

For an alkali-metal atom, the maximum potential depth is calculated from [?],

$$U_0 = \frac{\hbar\Gamma}{2}\frac{P\Gamma}{\pi W_0^2 I_0 \Delta} \tag{2}$$

where $\Gamma = 1/\tau$, is the natural linewidth and I_0, the saturation intensity, given by,

$$I_0 = \frac{\pi^2 hc\Gamma}{3\lambda^3} = \frac{\pi}{3}\frac{hc}{\lambda^3\tau}. \tag{3}$$

The numerical value of saturation intensity I_0 for D_2 line ($|F = 2, m_F = \pm 2\rangle \rightarrow |F' = 3, m_{F'} = \pm 3\rangle$) atomic transition of ^{87}Rb atoms is calculated to be 1.67 mW/cm^2=16.7 W/m^2 .

FREQUENCY-DETUNING AND POTENTIAL DEPTH USING LASERS OF DIFFERENT WAVELENGTH

Below is the table with numerical values of detuning and potential depth for dipole traps using laser lights of different wavelength.

wavelength nm	Detuning Δ	Potential Depth U_0 W/m^2
1064	$-25 \times 10^5\Gamma$	$1.53 \times 10^{-35}\frac{P}{W_0^2}$
850	$-6.93 \times 10^5\Gamma$	$5.5 \times 10^{-35}\frac{P}{W_0^2}$
820	$-3.46 \times 10^5\Gamma$	$11.04 \times 10^{-35}\frac{P}{W_0^2}$
800	$-0.6 \times 10^5\Gamma$	$63.66 \times 10^{-35}\frac{P}{W_0^2}$

Atoms in an intense laser field experience an ac start shift. This shift creates a potential U proportional to the light intensity, such that

$$U(r,z) = U_0\left[\frac{e^{\frac{-2r^2}{W(z)^2}}}{1+(\frac{z}{z_R})^2}\right] \tag{4}$$

at the focus of a Gaussian laser beam, with r and z being the radial and axial co-ordinates, $z_R = \frac{\pi W_0^2}{\lambda}$ is the Rayleigh range [?] at wavelength λ and beam waist W_0. $W(z)$ is the beam radius as a function of axial position z and is given by,

$$W(z) = W_0\sqrt{1+\left(\frac{z}{z_R}\right)^2}. \tag{5}$$

For a beam in horizontal direction the overall potential due to effect of gravity is given by,

$$U_g(r,z) = -mgr - U_0\left[\frac{e^{\frac{-2r^2}{W(z)^2}}}{\left(1+\frac{z}{z_R}\right)^2}\right] \tag{6}$$

MINIMUM POWER REQUIRED TO TRAP ^{87}Rb ATOMS AT DISTANCE z FROM THE FOCAL POINT OF THE BEAM

To calculate the minimum power required to trap ^{87}Rb atoms at distance z from the focal point of the beam in the axial direction, the above equation (Eq. **??**) is differentiated,

$$\frac{d^2U}{dr^2} = -mg + \frac{4U_0 r}{W(z)^2}\left[\frac{e^{\frac{-2r^2}{W(z)^2}}}{1+(\frac{z}{z_R})^2}\right] = 0 \tag{7}$$

$$\Longrightarrow r = \frac{mg}{4U_0}\frac{W(z)^2}{e^{\frac{-2r^2}{W(z)^2}}}\left[1+\left(\frac{z}{z_R}\right)^2\right] \tag{8}$$

By substituting the appropriate values for the above equation (Eq. **??**) one can calculate the minimum power required to trap atoms at distance z from the beam focus in the axial direction. Below is the table with the calculated power required to trap ^{87}Rb atoms using laser light with different wavelengths and beam waist, 50 μm, 100 μm and 200 μm.

For light with beam waist, $W_0 = 50\mu$m

Distance from focus	1064 nm	850 nm	820 nm
$z = 5$ cm	3.33 W	450 mW	210 mW
$z = 2$ cm	30 mW	37 mW	26.5 mW
$z =1$ cm	16 mW	8.4 mW	4 mW
$z = 0.5$ cm	11.6 mW	3.8 mW	1.5 mW
$z = 0$ cm	9 mW	2.7 mW	1.4 mW

for $W_0 = 100\mu$m

Distance from focus	1064 nm	850 nm	820 nm
$z = 5$cm	610 mW	110 mW	47 mW
$z = 2$cm	140 mW	31 mW	15 mW
$z = 1$cm	91 mW	23 mW	12 mW
$z = 0.5$cm	78 mW	22 mW	11 mW
$z = 0$cm	77 mW	22 mW	11 mW

for $W_0 = 200\mu$m

Distance from focus	1064nm	850nm	820nm
$z = 5$cm	1.53 W	200 mW	1.1 W
$z = 2$cm	650 mW	180 mW	900 mW
$z = 1$cm	610 mW	180 mW	900 mW
$z = 0.5$cm	600 mW	180 mW	900 mW
$z = 0$cm	600 mW	180 mW	900 mW

The maximum photon scattering rate Γ_{sc} is given by

$$\Gamma_{sc} = \frac{\Gamma}{\Delta}\frac{U_0}{\hbar} \tag{9}$$

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[3] D. Cho, J. Korean Phys. Soc., **30**, 373, (1997).

[4] Distance at which the diameter of the spot size increases by a factor of $\sqrt{2}$