Dynamic Effects in Optical Forces Produced by Adiabatic Rapid Passage

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Abstract

Numerical studies of large optical forces produced by adiabatic rapid passage on two-level atoms have been extended beyond our previous work and show strong sensitivity to sweep direction and relative optical phase.

Adiabatic Rapid Passage on the Bloch Sphere

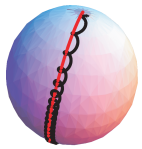
$$\vec{R} \equiv \{r_1, r_2, r_3\} \qquad \frac{d\vec{R}}{dt} = \vec{\Omega} \times \vec{R}$$

$$\Omega_1 \equiv \overbrace{\left|\Omega_0 \sin(\omega_m t)\right|}^{\Omega(t)} \cos\left(\overbrace{\frac{\delta_0}{\omega_m}}^{\delta(t)} \sin(\omega_m t) + \phi\right)$$

$$\Omega_2 \equiv \left|\Omega_0 \sin(\omega_m t)\right| \sin\left(\frac{\delta_0}{\omega_m} \sin(\omega_m t) + \phi\right)$$

$$\Omega_3 \equiv 0$$

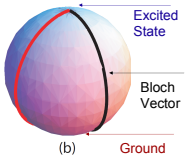
Traditional ARP
$\Omega_0 \sim \delta_0 >> \omega_m >> \gamma$



(a)

(δ_0/ω_m=30, Ω_0/ω_m=50)

Unconventional ARP
$\Omega_0 \sim \delta_0 \sim \omega_m >> \gamma$

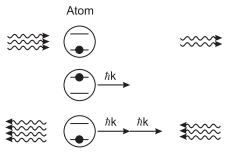


(b)

(1.10, 1.61)

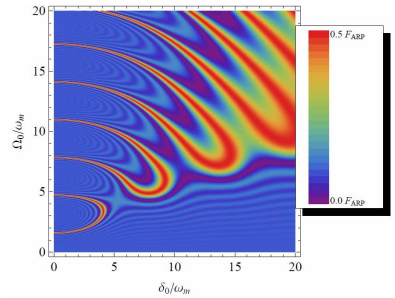
Extraordinarily Large Forces from Periodic ARP

Forces arise from the coherent exchange of momentum between an atom and counterpropagating optical fields. The first pulse leads to absorption while the other causes stimulated emission.

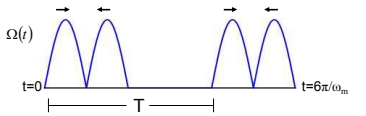


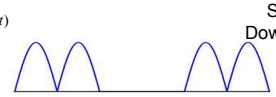
$$F_{ARP} \equiv \frac{\hbar k(\omega_m)}{\pi}$$ ← Experimental parameter

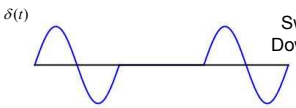
$$F_{rad} \equiv \frac{\hbar k(\gamma)}{2}$$ ← Atomic parameter

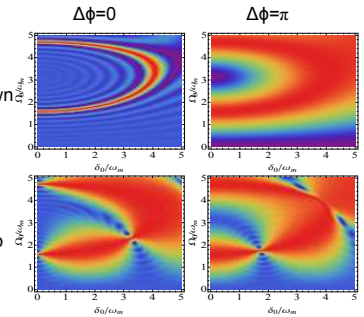


$$F \equiv \frac{\left(r_3(\pi/\omega_m) - r_3(0)\right) - \left(r_3(2\pi/\omega_m) - r_3(\pi/\omega_m)\right)}{8}$$









Δϕ is the relative phase of the optical fields

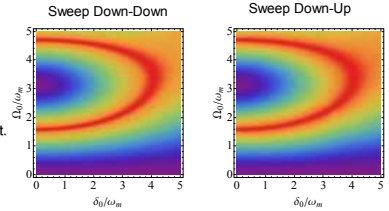
Averaging Over Δϕ

$$v_{trans} t_{int} >> \lambda$$

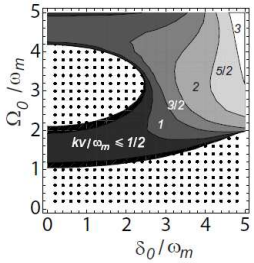
Atoms will experience various ϕ over many periods.

Average over Δϕ to obtain expected experimental result.

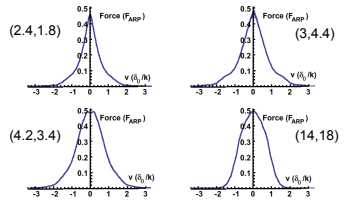
There is no difference between Sweep Down-Down and Sweep Down-Up when averaging over Δϕ.



Forces on Moving Atoms

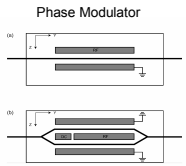


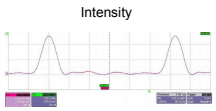
The black area shows the parameter values where the force exceeds $F_{ARP}/4$ for atoms at rest. Succeeding lighter areas indicate regions of velocity where the force exceeds $F_{ARP}/4$. The velocity increment between regions is $\omega_m/2k$ up to $v = 3\omega_m/k$ in the upper right.

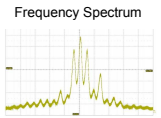


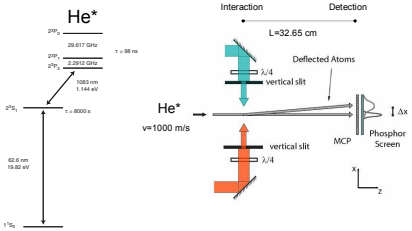
Velocity dependence of the ARP force for various values of the experimental parameters (δ_0/ω_m,Ω_0/ω_m). Plots were average over all Δϕ.

Experimental Implementation of ARP

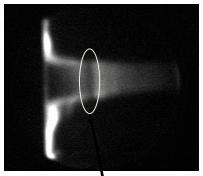








Phosphor Screen Image



Future Area of Interest

Further Reading

T. Lu, X. Miao, and H. Metcalf, Phys. Rev. A **75**, 063422 (2007).
T. Lu, X. Miao, and H. Metcalf, Phys. Rev. A **71**, R061405 (2005).
X. Miao, E. Wertz, M. Cohen, and H. Metcalf, Phys. Rev. A **75**, 011402 (2007).

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