Strong Optical Force Measurements Using Adiabatic Rapid Passage

Daniel Stack, John Elgin, Harold Metcalf

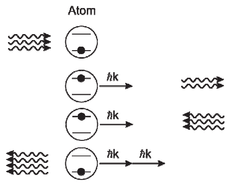
Stony Brook University, Stony Brook, NY 11794-3800

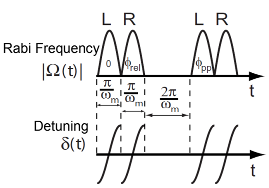
INTRODUCTION

Previous experimental work [1] has shown that very strong, long range optical forces can be produced on the $2^3S \rightarrow 2^3P$ transition in He through the use of ARP sequences in an unconventional parameter domain . These optical forces rely on the coherent momentum exchange between the atoms and the light field. We expand on this work to include the use of independent counter propagating optical beams which allow for increased control of the experimental parameters, such as Doppler detuning to simulate the velocity of moving atoms. We present our experimental setup and our investigation of the velocity dependence of this large optical force.

FORCE FROM PERIODIC ARP SEQUENCE

Coherent control of the momentum exchange between the light field and the atom is possible using precisely timed pulses that cycle the atom between ground and excited states. Large forces can result if this process is robust and is able to be carried out many more times in succession.





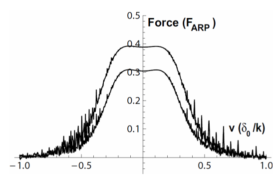
Chirping Frequency: ω_m = 160 MHz

Pulse Frequency: $\omega_m/2$ with 25% duty cycle (3.125 ns pulse length)

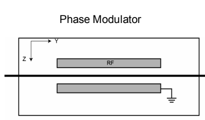
An ARP sequence consists of a left and right propagating chirped pulse interacting with an atom sequentially followed by a dead time of $2\pi/\omega_m$.

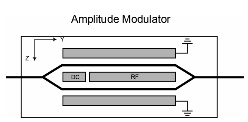
$$\overline{F}_{ARP} = \frac{\Delta p}{\Delta t} = \frac{2\hbar k}{2\pi/\omega_m} = \frac{\hbar k \omega_m}{\pi} \sim 32 F_{rad}$$

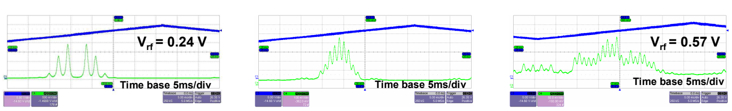
Forces suitable for laser cooling must have significant strength at some velocities and vanish at others. For the radiative force in the low intensity limit, v_c γ/k and is entirely dependent on the atomic properties. By contrast, the ARP force remains large for velocities where the Doppler shifts are well within the range of the frequency sweep as seen in the figure on the right. This means that velocity capture range for the ARP force, $v_c \sim \delta_0/k$, can be substantially increased by choosing $\delta_0 \gg \gamma$ so that it can be orders of magnitude larger than that of the radiative force.



FOURIER SPECTRUM FOR CHIRPED PULSES

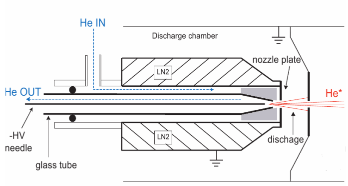


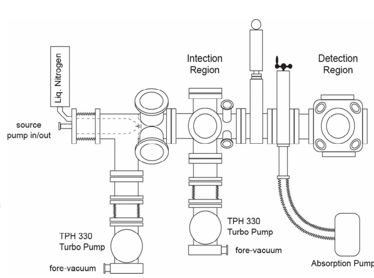




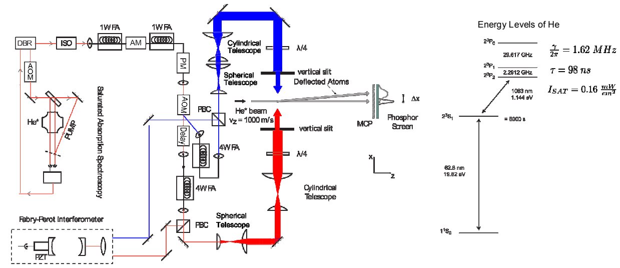
Phase Modulation 160 MHz **Amplitude Modulation 80 MHz** **Chirped Pulses**

VACUUM SYSTEM

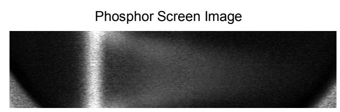


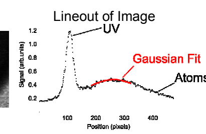


EXPERIMENTAL SETUP



MEASURING THE FORCE

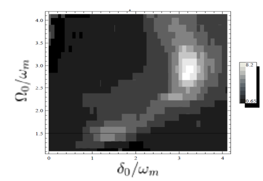




$$\frac{F_{ARP}}{F_{rad}} = \frac{m v_z^2 \Delta x}{L_{int} L_{flight}} \frac{2}{\hbar k \gamma}$$

Δx *is deflection* $L_{flight} = 35\ cm$

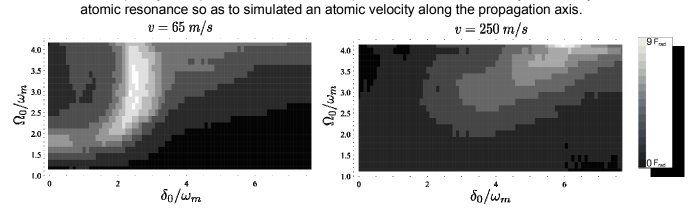
$L_{int} = 4\ mm$ $v_z = 1000\ m/s$

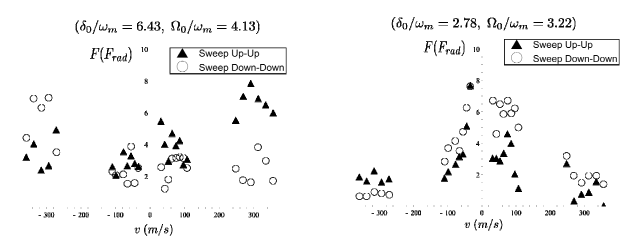


Optical force in units of the radiative force as a function of optical intensity and amplitude of the frequency sweep with both optical beams centered on atomic resonance.

VELOCITY DEPENDENCE of ARP

Optical force in units of the radiative force as a function of optical intensity and amplitude of the frequency sweep is shown below. The optical beams are detuned symmetrically about atomic resonance so as to simulated an atomic velocity along the propagation axis.





Shown above is the measured optical force as a function of atomic velocity for specific values of intensity and frequency sweep. The left figure has a very large frequency sweep and shows a force over a large velocity range. The figure on the right has a smaller frequency sweep and consequently smaller range in velocity. The force is not symmetric about v = 0 which may be due to an asymmetric pulse shape.

SUMMARY & OUTLOOK

- We have produced optical forces that are nearly an order of magnitude larger than the radiative force with He* by using many ARP sequences.
- These forces are non-zero for a much larger range of atomic velocities than the typical radiative force.
- Our next step will be to measure the velocity dependence of the ARP force for frequency sweeps up-down and down-up.

Further Reading

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

Supported by ONR and Dept. of Education