Abstract and Introduction

We are assembling a source of laser-cooled Rb atoms that can be launched at slow, controlled velocities and excited into Rydberg states. We assess the feasibility of detecting the motion of cold Rydberg atoms around a macroscopic charged wire.

The capture and ionization of cold ground-state atoms in a $1/r$-electric field has been observed previously [1], using a nanowire to ensure that captured atoms could move in free space at small radial distances before impacting the wire or field-ionizing near the surface. Using highly-excited atoms instead, we suggest that a macroscopic wire offers a robust system with magnified effects.

The capture cross-section increases for incident velocities and excited into Rydberg states. We propose that aspects of this model can be realized 10 times larger than for ground-state atoms. We could move in free space at small radial distances for atoms traveling at 2 m/s with a wire charged to +300 V, the critical impact parameter $r_0$ is too fast, the capture cross-section decreases. We propose that a reasonable set of parameters are $V_{\text{wire}} = 10 V$, $v_0 = 9$ m/s, $\alpha_{\text{laser}} = 150 \mu$m, and $n = 33$ (corresponding to a lifetime of 21 $\mu$s [2]).

Results and Considerations

The potential of the wire should be low so that $\alpha_{\text{ionization}} < \alpha_{\text{laser}}$. This condition also limits $n$. Given this constraint, $n$ should be large to extend the lifetime in the excited state. If the speed is too slow, the atom will decay before reaching the wire. If the speed is too fast, the capture cross-section decreases. We propose that a reasonable set of parameters are $V_{\text{wire}} = 10 V$, $v_0 = 9$ m/s, $\alpha_{\text{laser}} = 150 \mu$m, and $n = 33$ (corresponding to a lifetime of 21 $\mu$s [2]).

The next advancements will be to consider:
(i) paths of the ground-state atoms before excitation,
(ii) experimental scheme for excitation,
(iii) IMPORTANT effects for atoms in strong fields.

TOP ROW: initial speed $v_0 = 6$ m/s; MIDDLE ROW: $v_0 = 9$ m/s; BOTTOM ROW: $v_0 = 12$ m/s.

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Fundamental Physics

Assumption: the atom’s induced polarization scales linearly with field $E$ (weak field conditions).

Assumption: the interaction term in the Hamiltonian is given by $H_I = -\frac{\alpha}{r} E^2$

where $\alpha$ is the scalar polarizability (also called $\alpha_0$).

Strength of the $E$-field around infinite wire:

$E(r, V) = \frac{V_{\text{wire}}}{r \log (R_0 / R_1)}$

Expression for total energy:

Total Energy: $H = \frac{1}{2} m v_0^2 + L^2 / 2 m r_0^2$

where $v_0$ is the radial speed and $L$ is the angular momentum around the wire. We identify the critical angular momentum:

$L_{\text{crit}} = \frac{V_{\text{wire}} \sqrt{m m}}{\log (R_0 / R_{\text{wire}})}$

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Improving the Calculations

Recently we determined that +300V is too high. Current calculations use $V_{\text{wire}} = 10 V$. Below, we show trajectories for captured atoms for different initial speeds. Units are in microns ($\mu$m). For each speed, 6 values of $L < L_{\text{crit}}$ are shown. Colored segments correspond the portion of the path traversed in one lifetime of the Rydberg state. The dashed circle marks the location of classical ionization. The horizontal line marks the proposed location of the excitation laser, which should be outside the ionization radius but within the colored segment for all paths.

Parameters for a polarizable neutral atom in a weak external field.

We have been optimizing the values of:

$n$ – principal quantum number
$V_{\text{wire}}$ – the potential of the wire
$v_0$ – the initial speed of the launched atoms
$\alpha_{\text{laser}}$ – the location of the excitation beam

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