Scheme for Launching and Observing Dynamics of Cold Atoms in Rydberg States

Anne Goodsell[1], Erik Weidner[1], Mattias Fitzpatrick[1]

[1] *Middlebury College, Middlebury, VT 05753, USA*

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 atoms in high-n states. For a 20-micron-diameter wire charged to +300 V, the critical impact parameter for atoms traveling at 2 m/s with $n = 50$ is 30 μm, 10 times larger than for ground-state atoms. We propose that aspects of this model can be realized experimentally. Using an estimated lifetime of $40\ \mu$s* for the $n = 50$ state, we calculate that excitation must occur at r=100 μm, significantly beyond the wire's surface. In this way, we are preparing to promote launched atoms into high-n states and study their dynamics.

*Errata: in submission, lifetime was mistakenly stated as 40 ns. Improved estimates based on recent calculations give τ = 65 μ sec for the n=50 $S_{1/2}$ state of ^{85}Rb at 300 K [2].

[1] Goodsell, et al, PRL 104, 133002 (2010).
[2] Beterov, et al, PRA 79, 05204 (2009).

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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 $H_E = -\frac{1}{2}\alpha E^2$
where α is the scalar polarizability (also called α_0).

Strength of the $\vec{E}$-field around infinite wire:

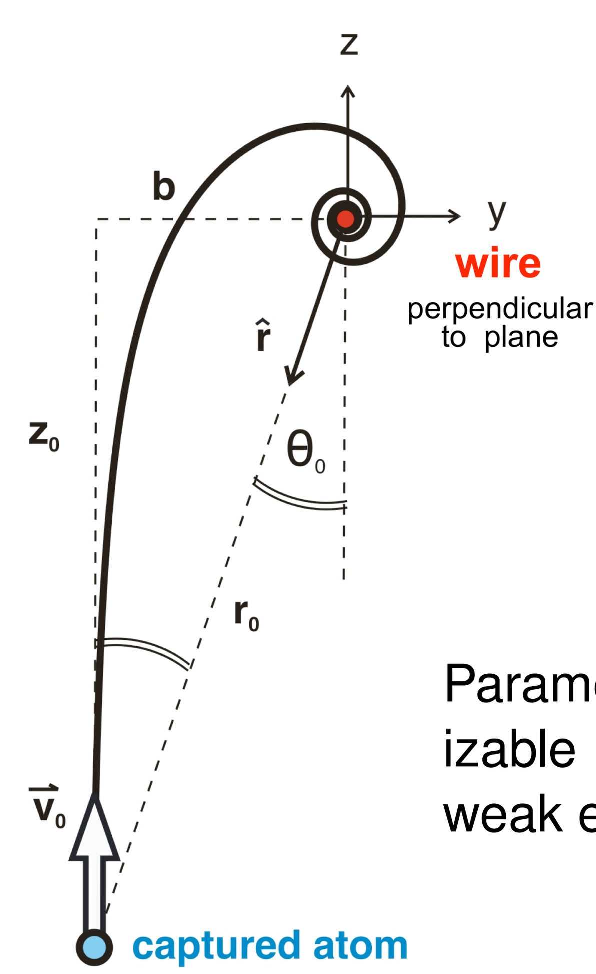
$$E(r,V) = \frac{V_{wire}}{r\,Log(R_0/R_{nt})}$$

Expression for total energy:

$$\textit{Total Energy} = H = \frac{1}{2}mv_r^2 + \frac{L^2 - L_{crit}^2}{2mr^2}$$

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

$$L_{crit} = \frac{V_{wire}\sqrt{\alpha m}}{Log(R_0/R_{wire})}.$$



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

We have been optimizing the values of:
n – principal quantum number
V_{wire} – the potential of the wire
v_0 – the initial speed of the launched atoms
z_{laser} – the location of the excitation beam

Improving the Calculations

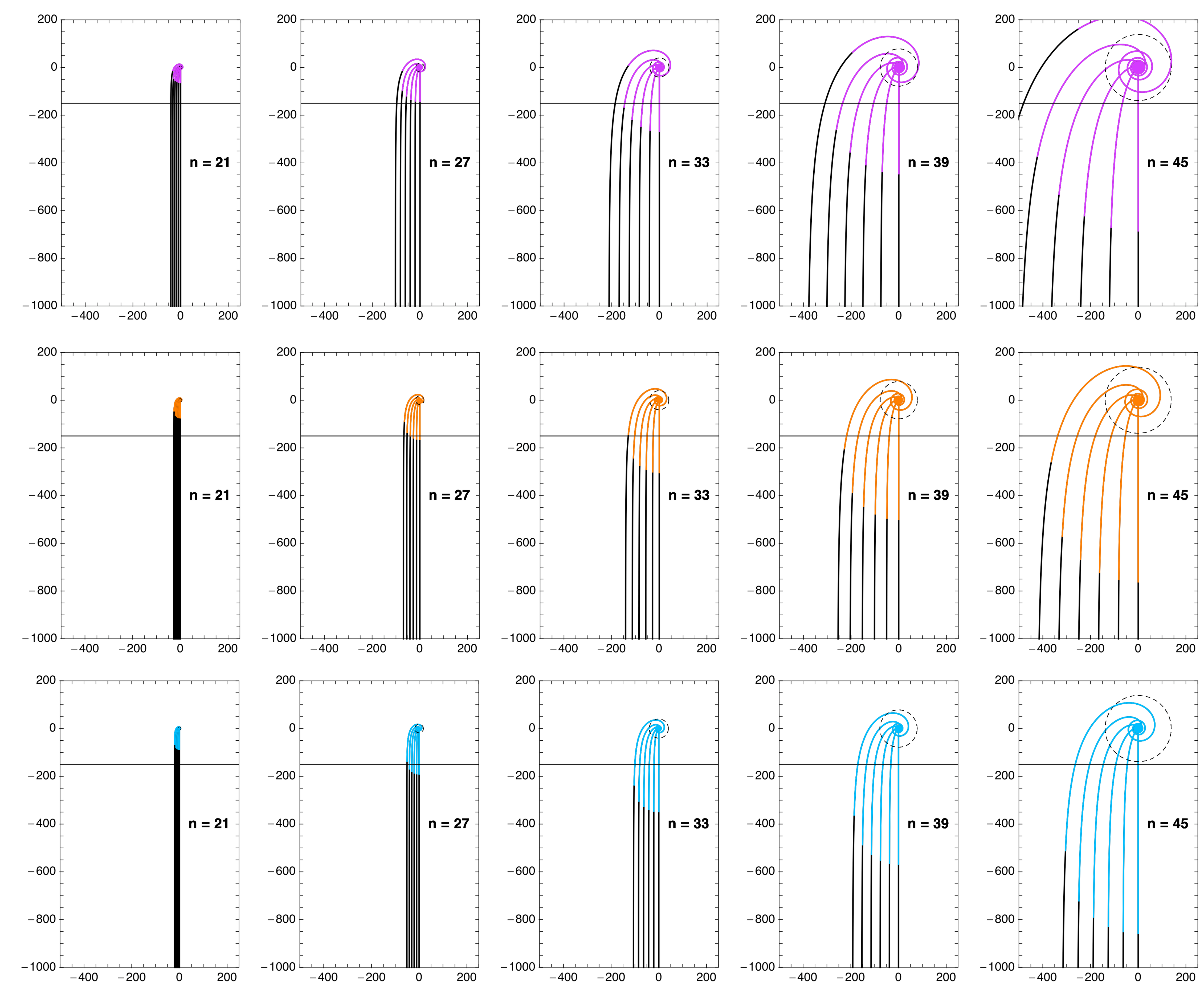
Recently we determined that +300V is too high. Current calculations use V_{wire} = 10 V. Below, we show trajectories for captured atoms for different initial speeds. Units are in microns (μm). For each speed, 6 values of $L < L_{crit}$ are shown. Colored segments correspond the portion of the path traversed 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.

Results and Considerations

The potential of the wire should be low so that $r_{ionization} < z_{laser}$. 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_{wire} = 10V, v_0 = 9 m/s, z_{laser} = 150 μm, and n = 33 (corresponding to a lifetime of 21 μsec [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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