Transient Effects in the Optical Pumping of Rubidium

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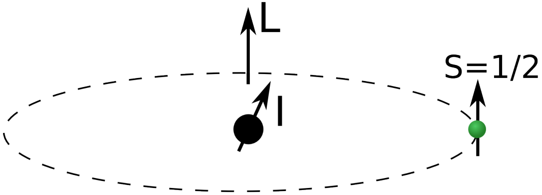
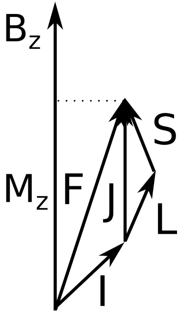
Transient Effects

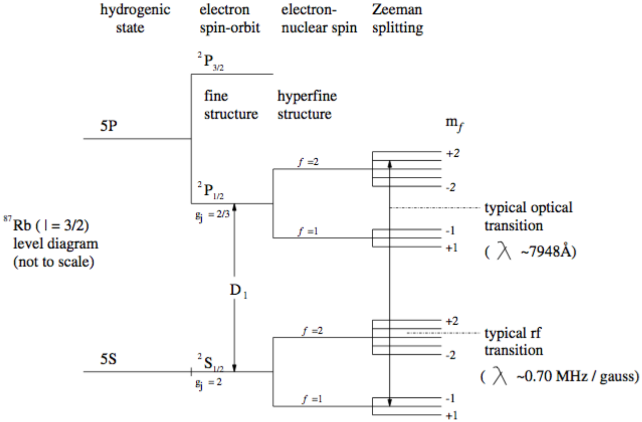
- Measurements of re-population rate with varying,
  - Light Intensity
  - Vapor Temperature
- Measurements of Rabi oscillation period with varying,
  - RF Amplitude
  - RF Frequency

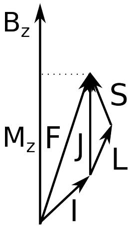
Energy Structure of Hydrogen-Like Atoms in a Magnetic Field B_z





Energy Structures of Rb^{87}





Photon Induced Energy Transitions in a Magnetic Field

Circularly-Polarized Light

$$\text{Right-Handed} \rightarrow \sigma^{+}$$
$$\text{Left-Handed} \rightarrow \sigma^{-}$$

$\Delta M_z = +1$

$$\mathbf{B_z} \cdot \sigma^{+} > 0 \qquad \Delta M_z = +1$$
$$\mathbf{B_z} \cdot \sigma^{-} < 0 \qquad \Delta M_z = +1$$

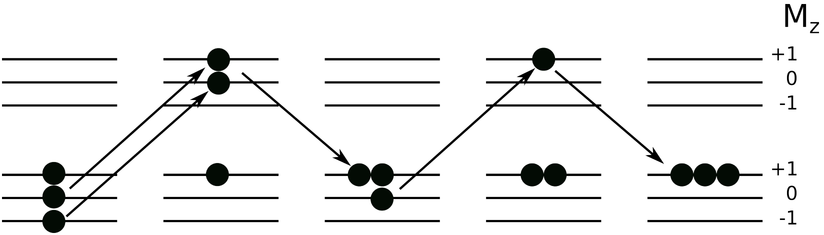
$\Delta M_z = -1$

$$\mathbf{B_z} \cdot \sigma^{+} < 0 \qquad \Delta M_z = -1$$
$$\mathbf{B_z} \cdot \sigma^{-} > 0 \qquad \Delta M_z = -1$$

Optical Pumping of Hydrogen

Right-Handed Circularly Polarized Light

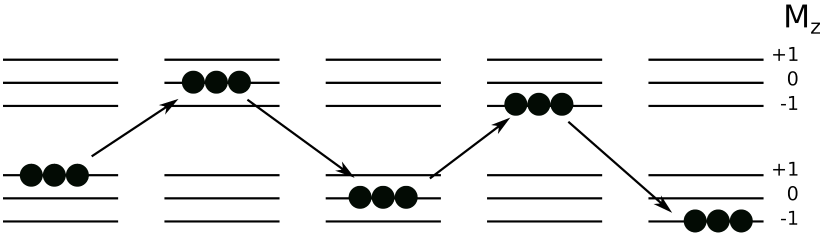
$\mathbf{B_z} \cdot \sigma^+ > 0$ $\Delta M_z = +1$



Optical Pumping of Hydrogen Following B_z Reversal

Right-Handed Circularly Polarized Light

$\mathbf{B_z} \cdot \sigma^+ < 0$ $\Delta M_z = -1$



Experiment Apparatus

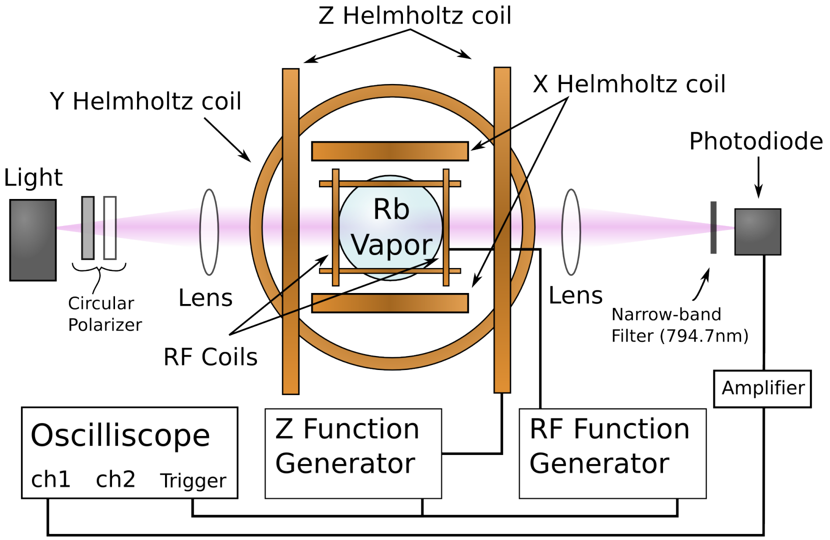
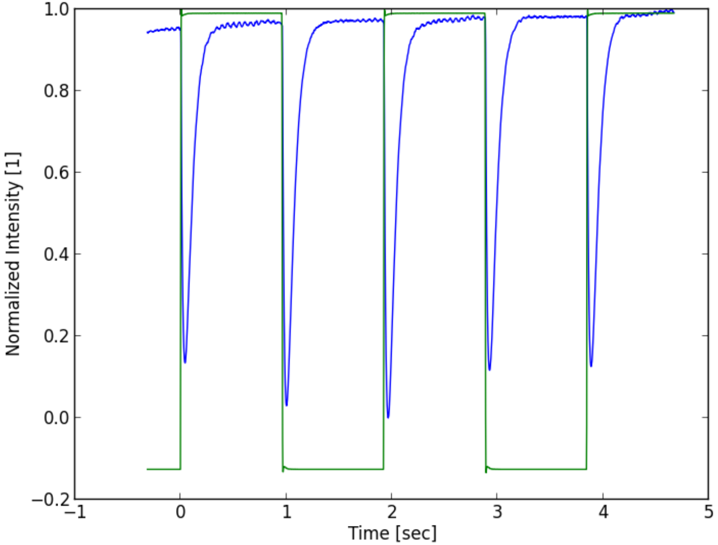
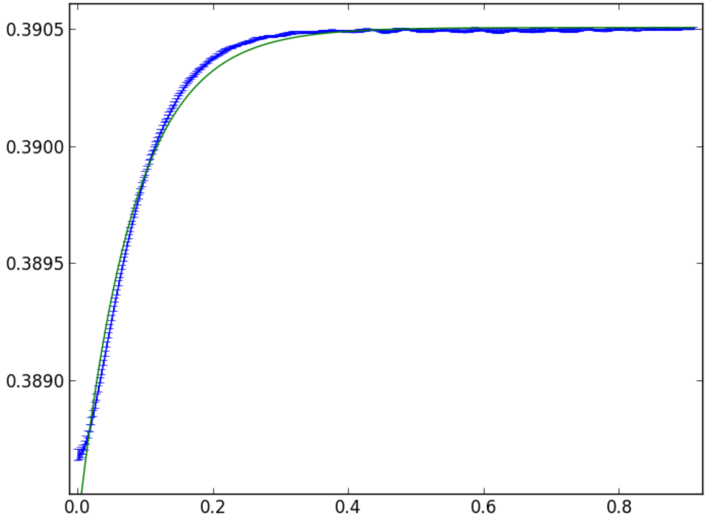


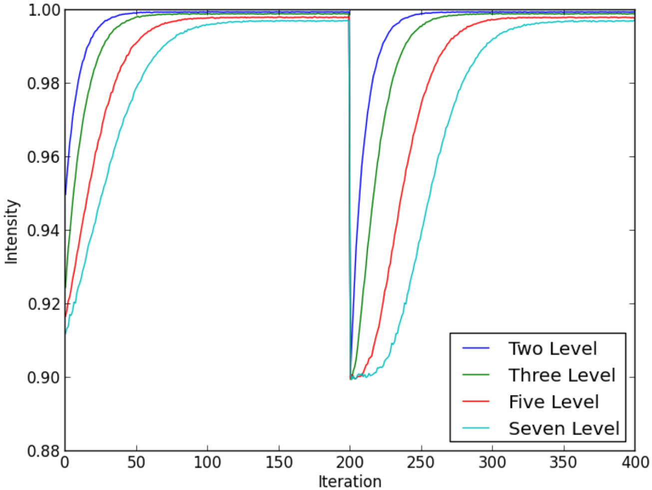
Photo-diode Voltage With B_z Current



Fit of Exponential to Re-population Signal



Simulation of Optical Pumping of Atomic Models with Different Numbers of M_z Levels



Towards a Functional Approximation for Rubidium Signal

Assuming a Hydrogen like, three M_z level structure,

$$\begin{aligned}
\frac{dn_1}{dt} &= n_0 a_0 \\
\frac{dn_0}{dt} &= -n_0 a_0 + n_{-1} a_{-1} \\
\frac{dn_{-1}}{dt} &= -n_{-1} a_{-1}
\end{aligned}$$

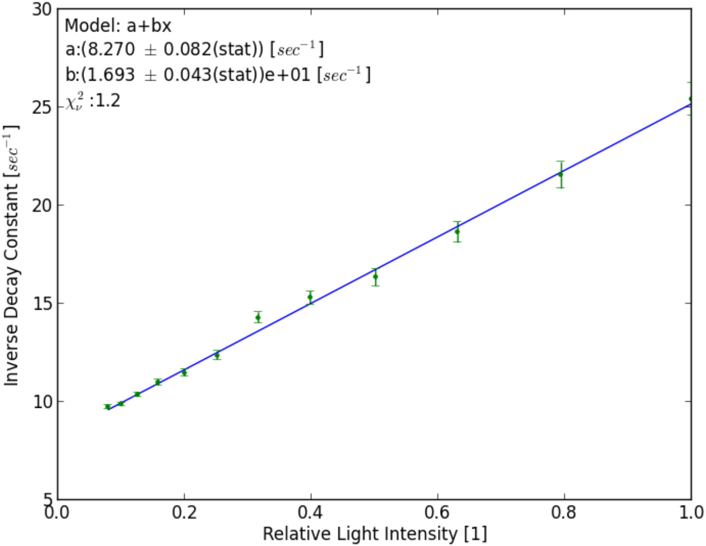
hence,

$$\frac{d^2 n_0}{dt^2} = -(a_{-1} + a_0)\frac{dn_0}{dt} - a_{-1} a_0 n_0$$

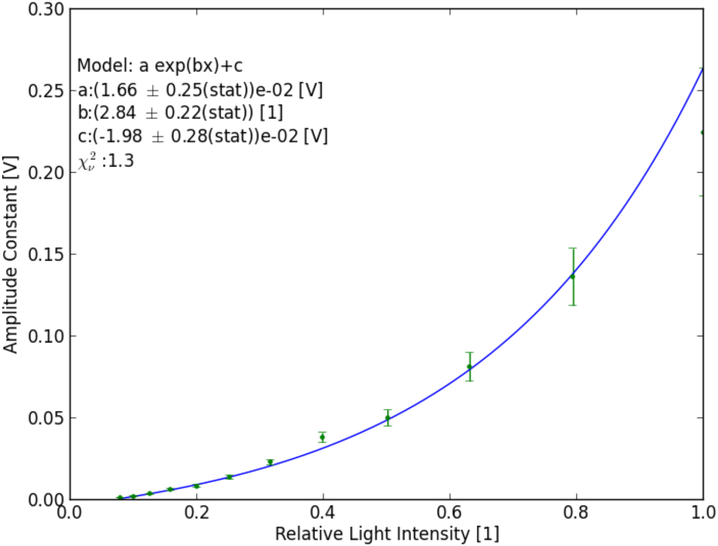
Assuming $a_{-1} = a_0$,

$$I(x) = c_4 - (c_0 t + c_1)\exp\left(-c_2(t - c_3)\right)$$

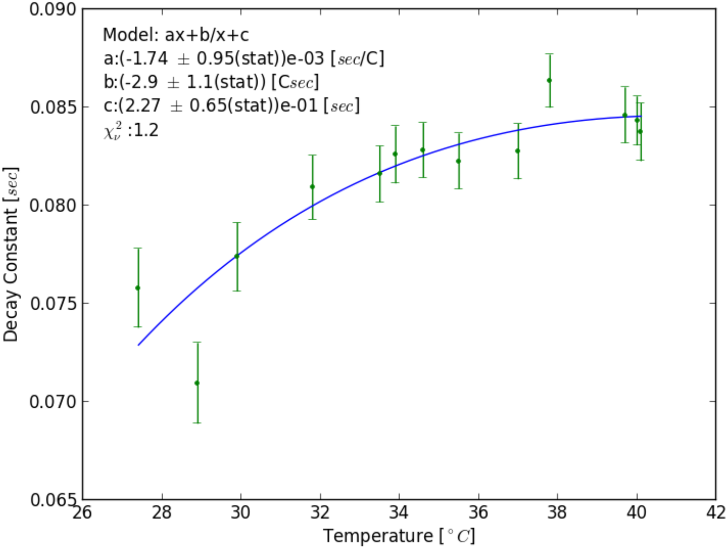
Dependency of Inverse Decay Time on Light Intensity



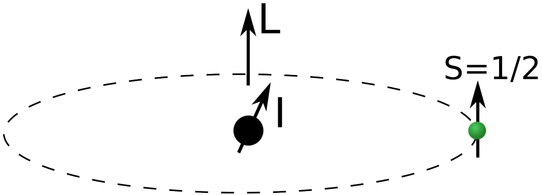
Dependency of Signal Amplitude on Light Intensity

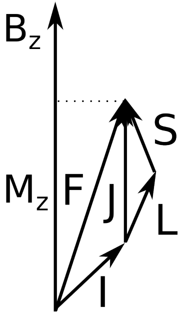


Dependency of Decay Time on Temperature



Classical Description of Rabi Oscillations





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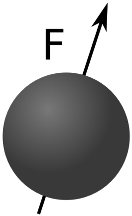

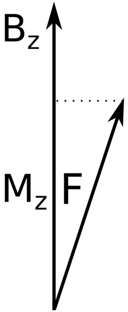

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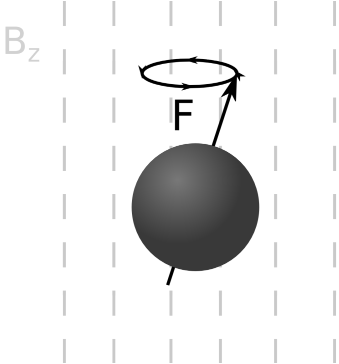
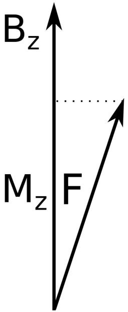
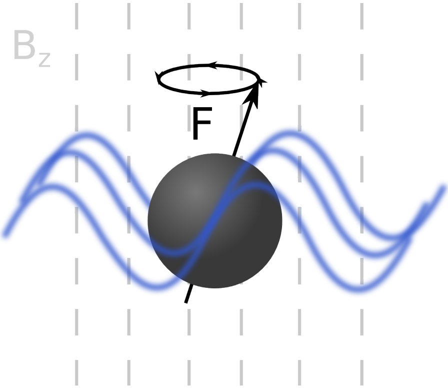


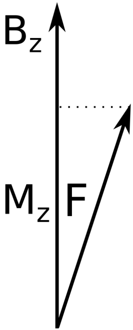


$$\omega_0 = \gamma B_0$$

$$\gamma = g_f \frac{\mu_0}{\hbar}$$

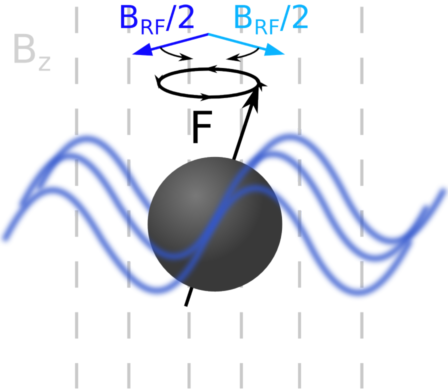
Classical Description of Rabi Oscillations

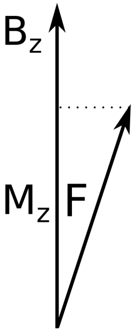




$$\omega_{RF} = \omega_0$$

Classical Description of Rabi Oscillations





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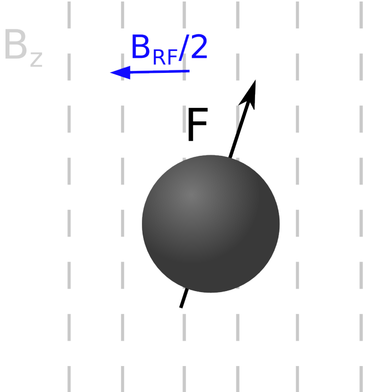

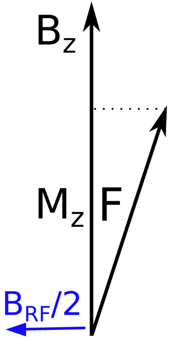

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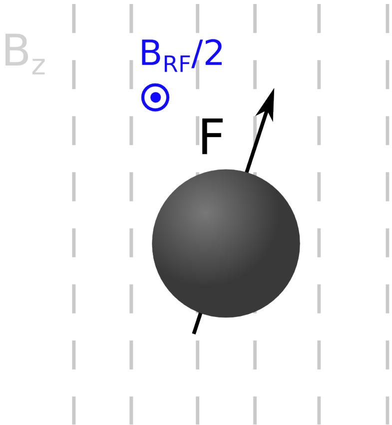
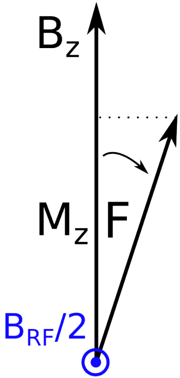




$$\omega_M = \gamma \frac{B_r f}{2} \qquad \rightarrow \qquad T = \frac{4\pi}{\gamma B_{RF}}$$

Theoretical Predictions for Period of Rabi Oscillations

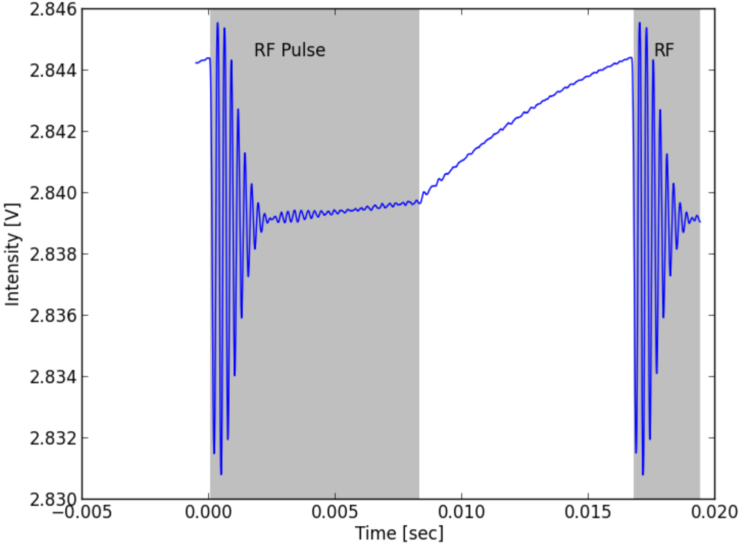
Key relationships,

$$T \propto \frac{1}{B_{RF}} \propto \frac{1}{V_{RF}}$$

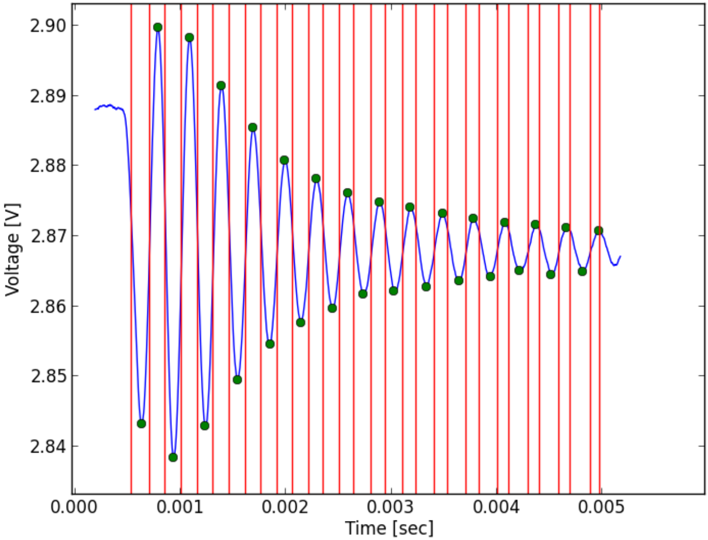
and,

$$\frac{T_{85}}{T_{87}} = \frac{\gamma_{87}}{\gamma_{85}} = \frac{g_{f87}}{g_{f85}} = \frac{3}{2}$$

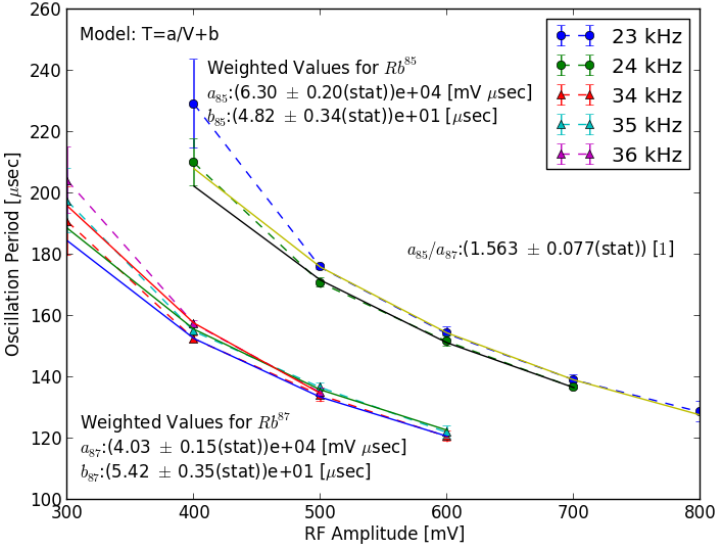
Rabi Oscillations Signal Overview



Rabi Oscillation Extraction of Period



Rabi Oscillation Period vs RF Amplitude



Rubidium Rabi Oscillation Period Ratio

$$\frac{T_{85}}{T_{87}} = \frac{a_{85}}{a_{87}}$$

Measured	Accepted	σ Off
(1.563 ± 0.077)[1]	1.50	0.81

Concluding Remarks

- Rabi oscillations would make a lovely addition to lab procedure