Relaxation Mechanisms in Optical Pumping ^{87}Rb and ^{85}Rb

Bhaskar Mookerji   Charles Herder

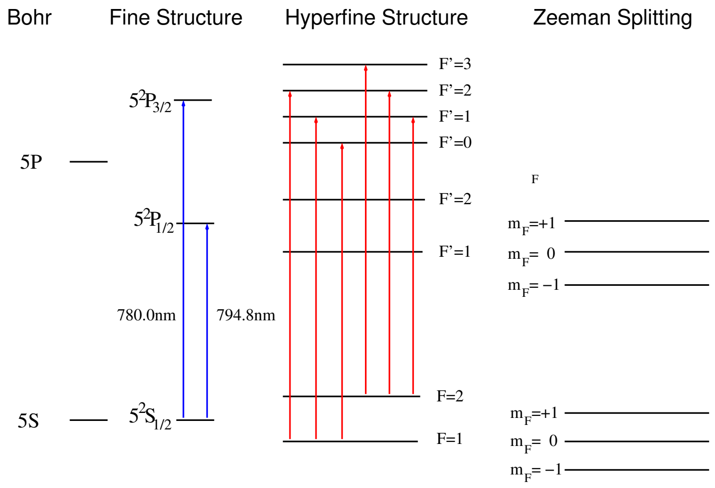
8.14 Experimental Physics II
MIT Department of Physics

18 April 2008

Goal:

- Measure the Zeeman shifts of rubidium isotopes and relaxation times of the excited states.
- We use a historical precursor to the laser: optical pumping of a vapor.

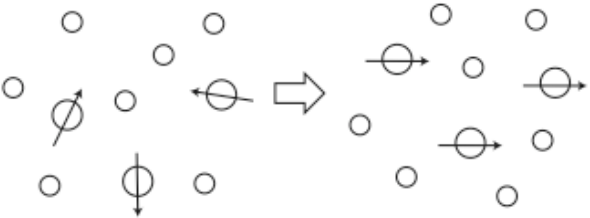
Outline

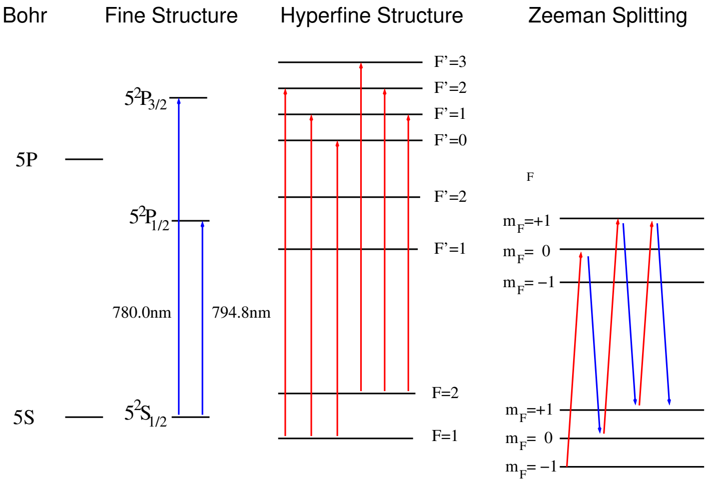


Boltzmann-distributed state populations

$E_z = g_f m_f \mu_B B$

Gas of polarized rubidium atoms with a buffer gas:





Boltzmann-distributed state populations altered by polarization-dependent selection rules: $\Delta m_f = \pm 1, 0$ (Spontaneous emission), $\Delta m_f = 1$ (Absorption)

We define dynamical variables for state transitions:

- n — Population of $m_F = 1$ state
- N — Population for $m_F \neq 1$ (non ground-state sublevels)
- $W_u dt$ — Probability for upward transitions to $m_F = 1$ (via optical pumping)
- $W_d dt$ — Probability for downward transitions from $m_F = 1$ (via collisions)

Rate equations for populations

$$\frac{dN}{dt} = nW_d - NW_u \qquad \frac{dn}{dt} = NW_u - nW_d \tag{1}$$

with solutions,

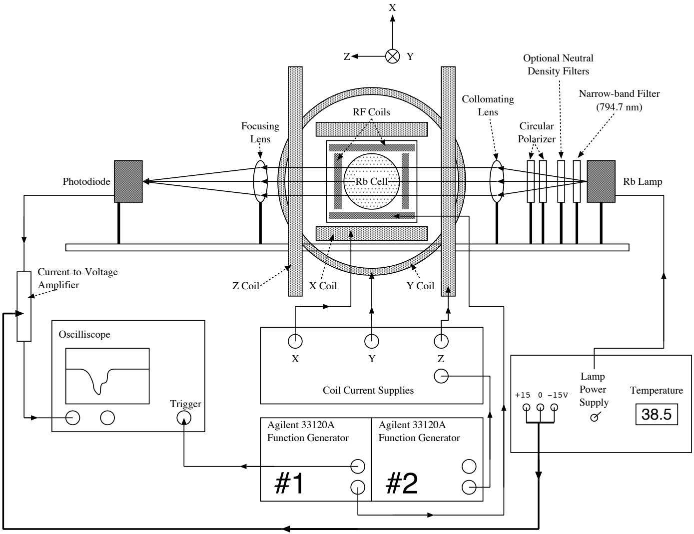
$$n = n_0 + C\left(1 - e^{t/\tau}\right) \qquad N = N_0 - C\left(1 - e^{t/\tau}\right), \tag{2}$$

where $\tau = (W_u + W_d)^{-1}$ and $C = \tau\,(N_0 W_u - n_0 W_d)$.

Quantifies measured intensity

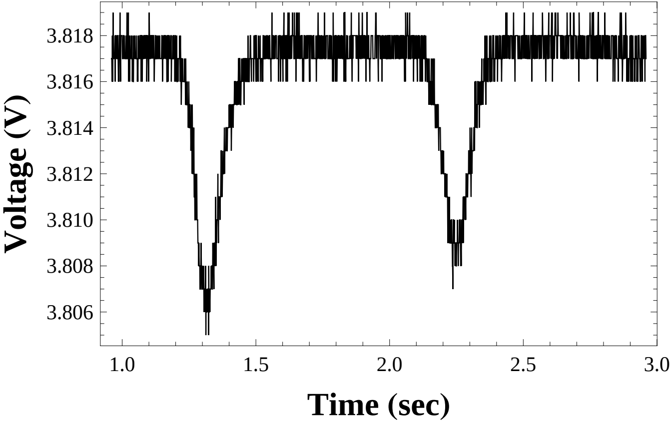
$$I = \alpha\,(n - N) = I_\infty - \alpha C e^{-t/\tau}, \tag{3}$$

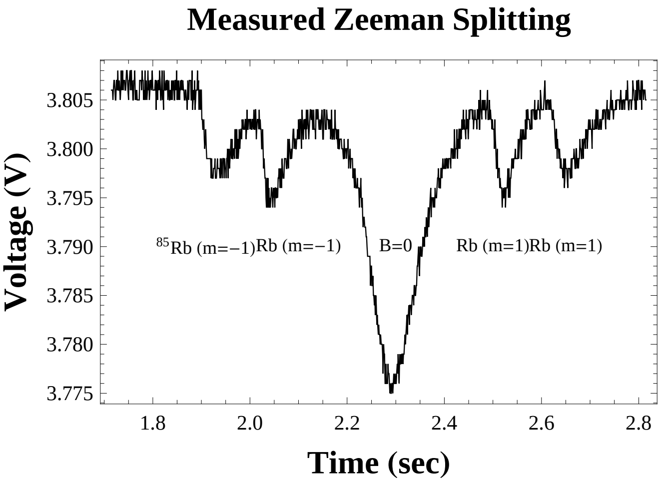
where $\alpha C = I_\infty - I_0$.


X
Z
Y
Optional Neutral
Density Filters
Narrow-band Filter
(794.7 nm)
Collomating
Lens
RF Coils
Focusing
Lens
Circular
Polarizer
Photodiode
Rb Cell
Rb Lamp
Current-to-Voltage
Amplifier
Z Coil
X Coil
Y Coil
Oscilliscope
Trigger
X
Y
Z
Coil Current Supplies
+15 0 -15V
Lamp
Power
Supply
Temperature
38.5
Agilent 33120A
Function Generator
#1
Agilent 33120A
Function Generator
#2

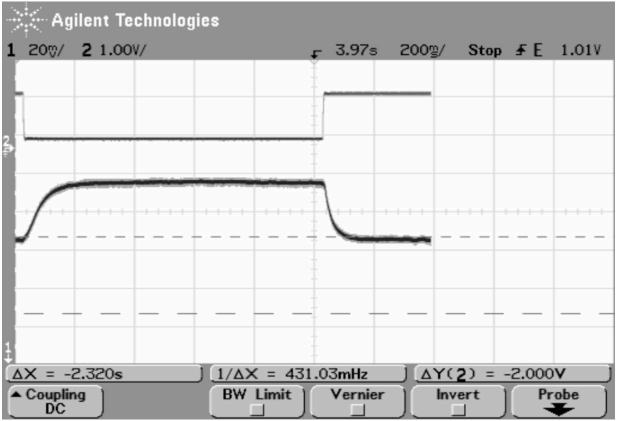
1. X, Y, and Z Helmholtz coils cancel ambient field
2. Two signal generators: RF coils induce transitions, Z coil pulse Zeeman transition

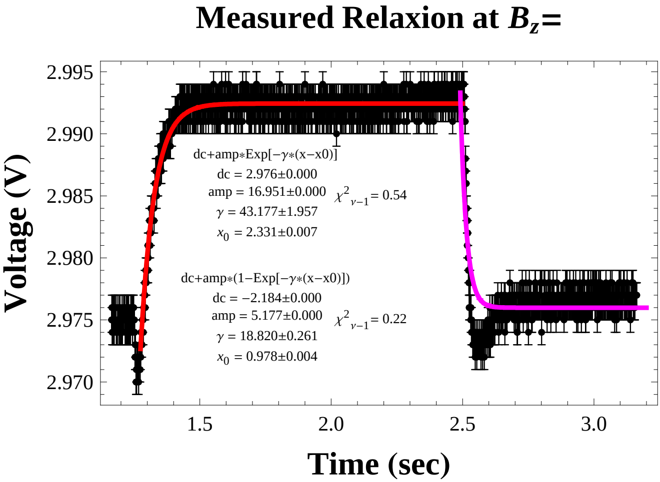
Measured Resonances at Ambient Field



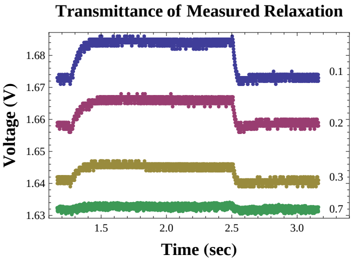


Weak field Zeeman splitting: $E = E_0 + g_f m_f \mu_B B \rightarrow B = \hbar\omega_{\rm RF}/g_f m_f \mu_B$.

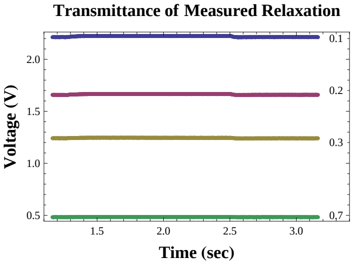

Agilent Technologies
1 20mV/ 2 1.00V/
3.97s 200ms/ Stop E 1.01V
ΔX = -2.320s
1/ΔX = 431.03mHz
ΔY(2) = -2.000V
Coupling DC
BW Limit
Vernier
Invert
Probe


Measured Relaxion at B_z=
Voltage (V)
Time (sec)
2.995
2.990
2.985
2.980
2.975
2.970
1.5
2.0
2.5
3.0
dc+amp∗Exp[−γ∗(x−x0)]
dc = 2.976±0.000
amp = 16.951±0.000
$\chi^2_{\nu-1}$ = 0.54
γ = 43.177±1.957
x_0 = 2.331±0.007
dc+amp∗(1−Exp[−γ∗(x−x0)])
dc = −2.184±0.000
amp = 5.177±0.000
$\chi^2_{\nu-1}$ = 0.22
γ = 18.820±0.261
x_0 = 0.978±0.004

Optical Attenuation (at 44.3°)

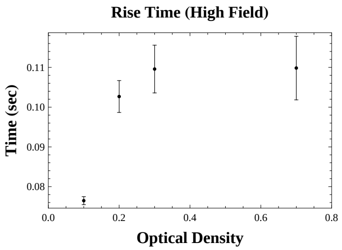


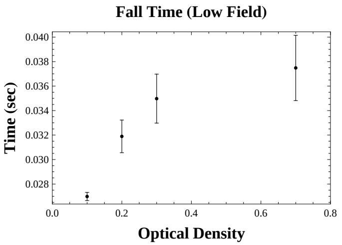
Time constant

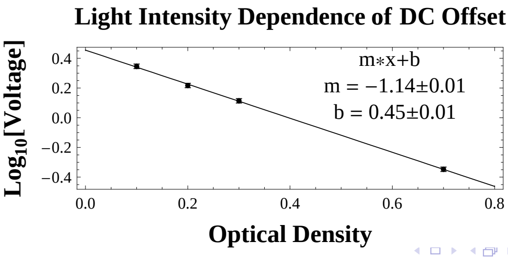


DC offset

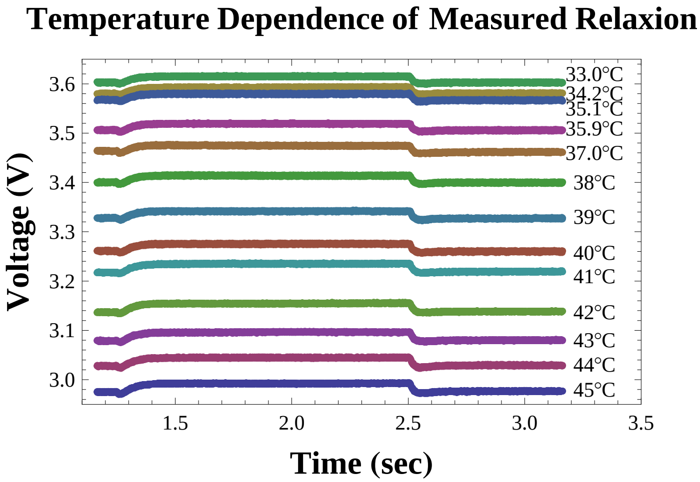
Optical Attenuation



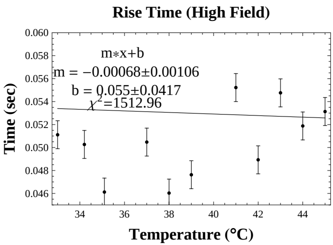


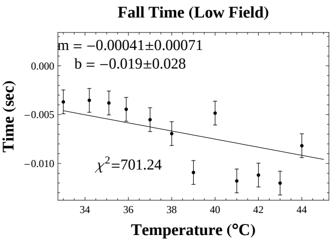


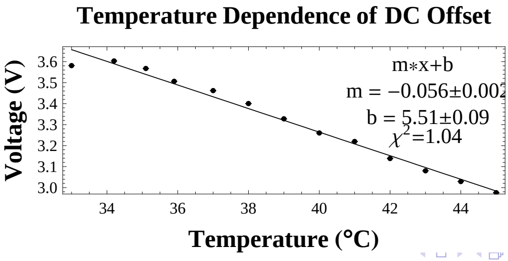
Lamp Temperature



Lamp Temperature







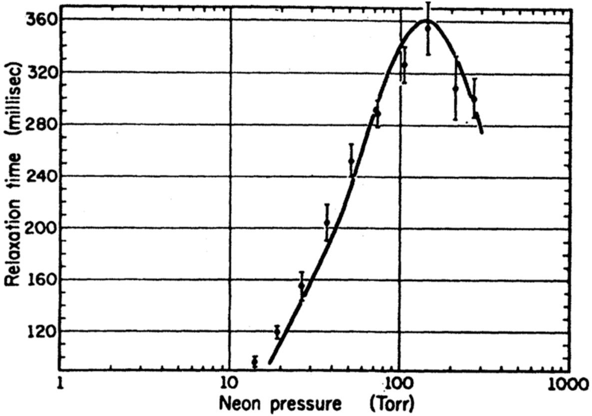


FIG. 25. Pressure dependence of the relaxation rate of polarized cesium atoms when both diffusion to the walls and collisional relaxation are present [from (Fra64b)].

W. Happer, Rev. Mod. Phys, April 1972.

- Scope error from sampling time and resolution, signal to noise ratio
- Additional noise: ambient lighting, mechanical oscillations
- Difficulty in controlling lamp Variac
- Errors in relaxation time and DC offset given by fit values

Summary

- Error analysis: Data agrees qualitatively.
- Zeeman splitting
- Parameter dependence of
  - Magnetic field strength
  - Optical density
  - Temperature