Measuring the Zeeman Effect in Mercury Vapor

Shawn Westerdale

MIT - Department of Physics

Outline

- Goals and Objectives
- What is the Zeeman Effect?
- On Landé g-Factors
- Experimental Setup, The Procedure, and the Fabry-Perot Interferometer
- Zeeman Splitting: Results and Observations
- Error Analysis

Goals and Objectives

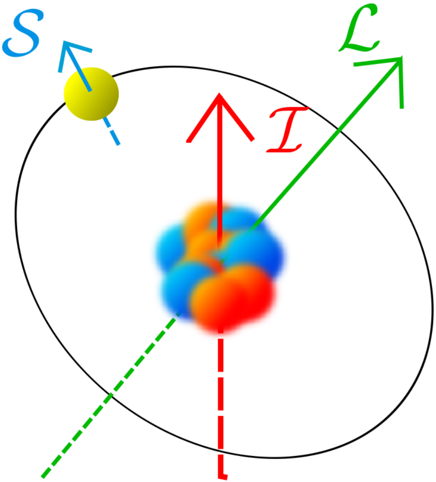
- Observe Zeeman splitting in the 5461Å, 5770Å, and 5791Å spectral lines in Hg vapor
- Determine the Landé g-factors for these transitions

What is the Zeeman Effect?

Angular Momentum in the Atom

Total Angular Momenta

- $J = \vec{L} + \vec{S}$
- $F = \vec{J} + \vec{F}$



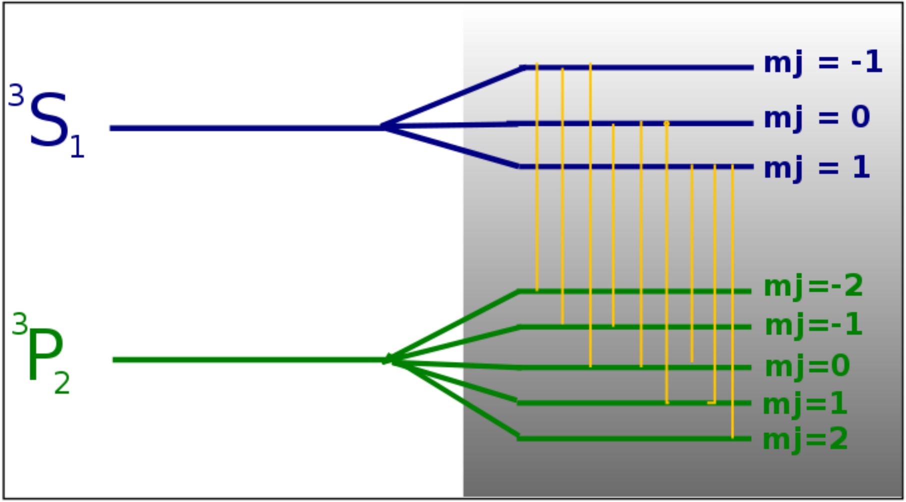
Angular Momentum Components

- $m_{\mathcal{S}}$
- $m_{\mathcal{L}}$
- $m_{\mathcal{I}}$
- $m_{\mathcal{J}}$
- $m_{\mathcal{F}}$

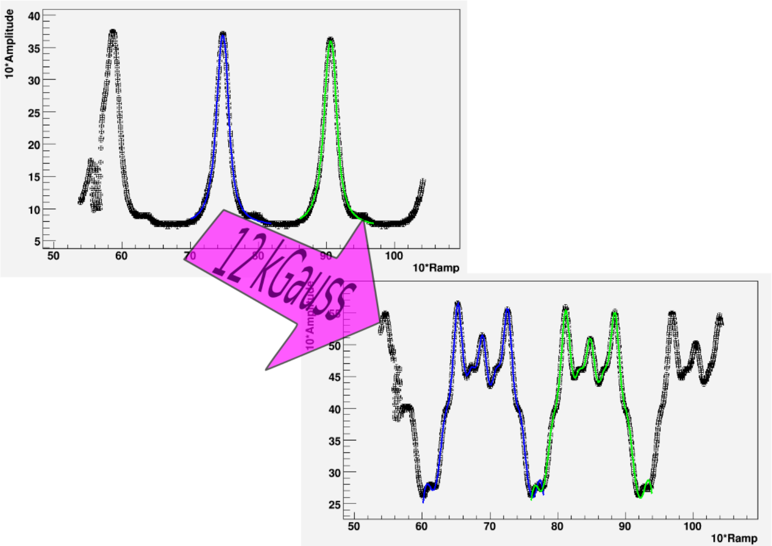
$m_{\mathcal{K}}$: $\{-k, \ldots, 0, \ldots, k\}$

What is the Zeeman Effect?

Fine Splitting in a Magnetic Field



What is the Zeeman Effect?
Splitting Example



On Landé g-Factors

What they are

Energy Change in B-Field

$$\Delta E = \frac{e}{2m_e}\left(\vec{L} + 2\vec{S}\right) \bullet \vec{B}$$

Introducing $\vec{J}$ to account for precession and simplifying with trigonometry reduces to...

Energy Level Shift

$$\Delta E = g_L m_j \mu_B B$$

where

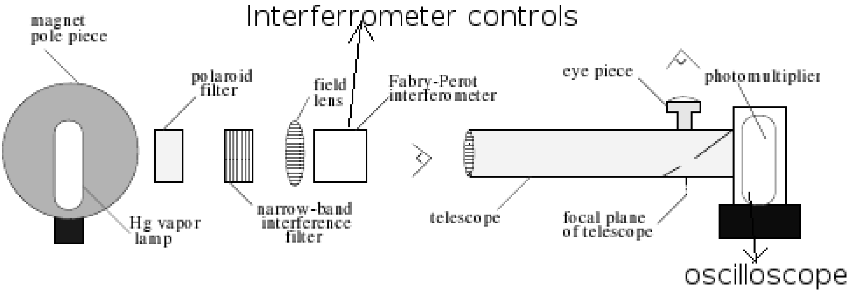
$$g_L = 1 + \frac{j(j+1) + s(s+1) - l(l+1)}{2j(j+1)}$$

On Landé g-Factors

Predictions for the 5461Å line

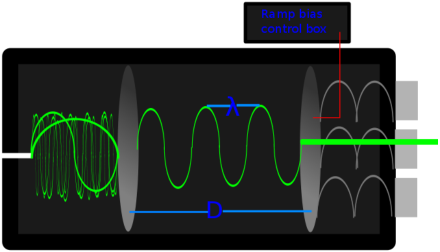
For $^3S_1$: $g_L = 2$
For $^3P_2$: $g_L = \frac{3}{2}$
$g_{eff} = \frac{3}{2} m_j - 2m_j'$

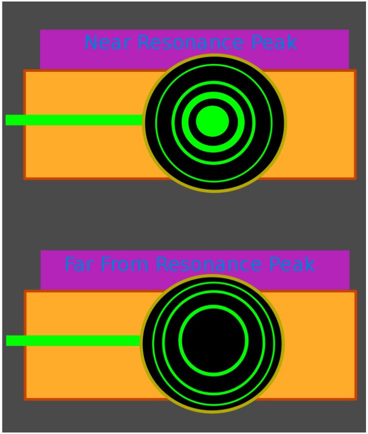
m_j	$m_j\prime$	Δm_j	g_{eff}
1	0	-1	-2
0	-1	-1	$-\frac{3}{2}$
-1	-2	1	-1
1	1	0	$-\frac{1}{2}$
0	0	0	0
-1	-1	0	$\frac{1}{2}$
1	2	1	1
0	1	1	$\frac{3}{2}$
-1	0	1	2


Interferrometer controls
magnet pole piece
polaroid filter
field lens
Fabry-Perot interferometer
eye piece
photomultiplier
Hg vapor lamp
narrow-band interference filter
telescope
focal plane of telescope
oscilloscope

Experimental Setup, The Procedure, and the Fabry-Perot Interferometer

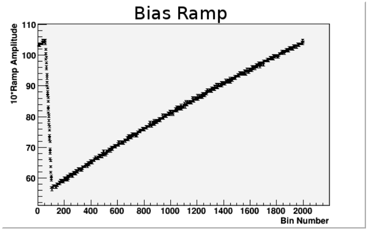
The Fabry-Perot Interferometer

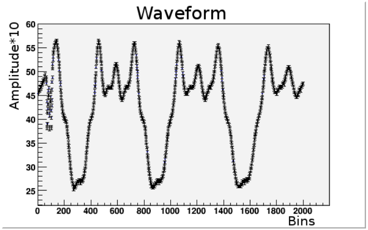




Zeeman Splitting: Results and Observations

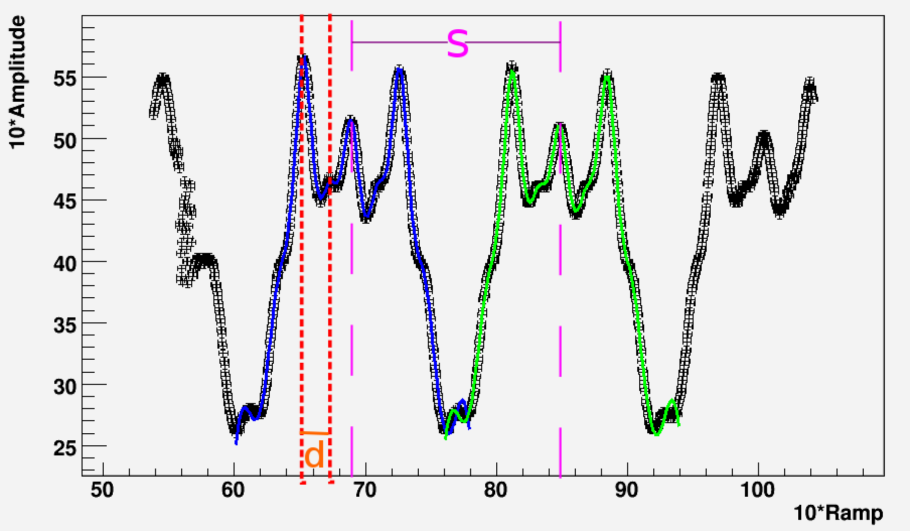
Data





Zeeman Splitting: Results and Observations

Data



Zeeman Splitting: Results and Observations

X-Axis Calibration

Condition for resonance:

$$D_n = \frac{n}{2}\lambda$$

Distance between consecutive resonance peaks:

$$\Delta D = \frac{1}{2}\lambda \rightarrow s$$

Conversion factor units of ramp amplitude to distance:

$$1[RU] = \frac{\lambda}{2Ds}[\text{distance}]$$

Measure Zeeman splitting of d in ramp units $\Rightarrow$

$$\Delta\nu = \frac{d\lambda}{2Ds}$$

B-Field Shifting

$$\Delta\nu = \Delta g_{eff} \frac{\mu_B}{hc} B$$

From:

$$\Delta E = g m_j \mu_B B$$
$$E = hc\nu$$

Zeeman Splitting: Results and Observations

Matching Results

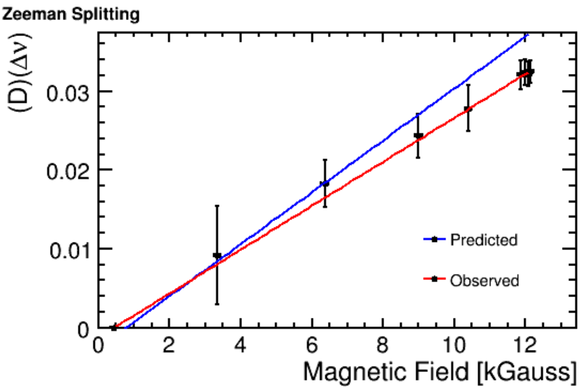


Figure: χ^2 for fitting predictions with known value of $\Delta g_{eff} = \frac{1}{2}$ is 58

Zeemann Splitting: Results and Observations

Conclusions

- Fell within bounds of Zeeman prediction, considering uncertainties
- For 5461 Å : $\Delta g_{eff} = 0.4 \pm 0.1$
  - Within σ of predicted value
  - Saw all transitions
- For 5770 Å : $\Delta g_{eff} = 0.9 \pm 0.4$
  - Within $\frac{\sigma}{3}$ of predicted value
  - Resolved $m_j = 0 \rightarrow m_j = \pm 1$ peaks
- For 5791 Å : $\Delta g_{eff} = 0.8 \pm 0.3$
  - Within σ of predicted value
  - Resolved all peaks, modulo degeneracy

Error Analysis

Systematic

- Mirror spacing : 0.59 mm
- Magnetic Field Offset : 0.44 kilogauss
- Digitization of oscilloscope : .32 millivolts
- Ramp nonlinearity $\approx$ .01%

Error Analysis
Random

- Fitting errors : $\approx 10\%$
- Magnetic field uncertainty : .1

Acknowledgements

We would gratefully like to thank the Junior Lab faculty for helping us understand this experiment and learn what to do