Lab 4: Zeeman Effect

Kevin Chang
(Dated: May 29, 2020)

I. INTRODUCTION

Named after Dutch physicist Pieter Zeeman, this phenomenon is the splitting of a spectral line when subject to a static magnetic field. That is, when viewing spectral lines through a device such as a Fabry-Perot Interferometer such as in this experiment, what normally looks like a single ring will split apart into several rings when subject to a magnetic field.

This effect can be categorized as normal and anomalous, named due to the absence of an explanation for the effect when it was first discovered. This experiment will observe normal Zeeman splitting, and the beginnings of anomalous Zeeman splitting through the use of a Fabry-Perot Interferometer.

II. EXPERIMENTAL METHODS

With the Fabry-Perot Interferometer, the mirror spacing is shifted slightly through the use of a piezoelectric actuator, allowing for precise and well-controlled movement of the mirror. The light is then passed through a beam splitter to both allow for the manual observation of rings in the laboratory, as well as digital recording of data through the use of a photomultiplier tube with a pinhole centered on the spot the rings pass through as the mirror spacing is changed.

The digital data was then plotted in MATLAB to produce a figure such as in figure 1. A findpeaks() function with a minimum peak prominence argument of 0.3 in MATLAB was used to automatically find the x-coordinates in the data. Missing data, such as the lesser peaks farther away from the tall, repeating central peaks in figure 1 were manually sampled in MATLAB. Manual sampling of peaks was determined to have very little uncertainty, as often the peaks had only a single data point that was a very obvious peak, with all subsequent data points to its left and right both decreasing; noise did not obscure the peak location.

The average peak separation in units of time were found by averaging the time difference between the four most intense, best defined peaks that appear in the graph. Data on the right that was obviously different than expected separation, such as the right-most cluster of points in figure 1 were ignored, as its separation was very apparently the result of hysteresis from the piezoelectric actuator used to move the mirror.

Given that the free spectral range is the separation in units time of the repeating peaks, as well as defined to be $c \div (2d)$ where d is the mirror separation ($1.7mm$), one may obtain a conversion constant, allowing for the

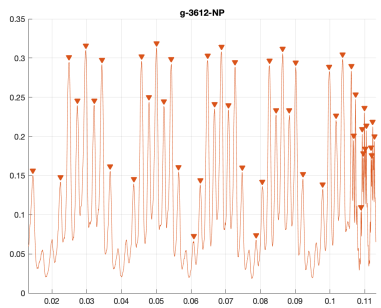

FIG. 1. Green Line with No Polarization

analysis of frequency separation of two peaks generated from light of very similar wavelength, such as the Zeeman splitting investigated in this experiment.

With μ_B being the Bohr magneton and B being the magnetic field, which may be calculated by using the calibration curve allowing for conversion of Amps to magnetic field strength, frequency shifts and energy shifts can be experimentally obtained from the digital scans produced from the photomultiplier tube, and compared to the expected energy shifts for all sets of data.

III. RESULTS

Average separations in units time obtained for green lines was $0.0189s$, and for yellow lines of wavelength $576.97nm$ and $579.07nm$ respectively were $0.02043s$ and $0.01977s$. Calibration constants for green lines was found to be $4.595 \times 10^{12}s^{-2}$ and for yellow lines of wavelength $576.97nm$ and $579.07nm$ respectively were found to be $4.2602 \times 10^{12}s^{-2}$ and $4.404 \times 10^{12}s^{-2}$ respectively. The following energy and frequency shifts observed for green, yellow (576.96 nm), and yellow (579.07 nm) lines can be found in tables I, II, and III respectively.

IV. DISCUSSION OF RESULTS

A. Measured Energy and Frequency Shifts

It appears that values of measured energy shift for the green line as can be seen in table I are relatively close to the expected values, with none of them deviating more than $0.2\mu_B B$. Results for yellow lines of wavelength 576.96 are also relatively close, and symmetric. i.e., They both are farther away from the expected energy shifts of $\pm 7/6\mu_B B$ by roughly $0.08\mu_B B$, but they

TABLE I. Green Line: 546.07 nm

Expected Energy Shift $[\mu_B B]$	Measured Energy Shift $[\mu_B B]$	Measured Frequency Shift $[\mu_B B \times 10^{33} s^{-1}]$	Initial m_J	Final m_J
-2	-2.002	-3.022	-1	0
-1.5	-1.515	-2.287	0	1
-1	-0.9966	-1.504	1	2
-.5	-0.4894	-0.7386	-1	-1
0	0	0	0	0
.5	0.5130	0.7742	1	1
1	0.9846	1.486	-1	-2
1.5	1.492	2.251	0	-1
2	1.960	2.957	1	2

TABLE II. Yellow Line: 576.96 nm

Expected Energy Shift $[\mu_B B]$	Measured Energy Shift $[\mu_B B]$	Measured Frequency Shift $[\mu_B B \times 10^{33} s^{-1}]$	Initial m_J	Final m_J
-1.1667	-1.250	-1.886	-1	0
0	0	0	0	0
1.1667	1.250	1.886	1	0

are off by the same amount. Similarly, results for yellow lines of $579.07nm$, which can be seen in table III are relatively close, however the furthest deviation is $0.15\mu_B B$ away from the expected energy shift; the deviations for expected values -1 and +1 are not evenly spaced; it appears that the peak for +1 energy shift is shifted away from the expected peak about twice as far as how much the -1 peak is shifted away from the expected peak.

This uneven spacing observed in III may possibly be due to the hysteresis of the piezoelectric actuator used to drive the mirror. Peaks appearing later in time on the graph (to the right) appears to be more impacted than peaks appearing at the start, and as such the last set of peaks included for analysis in the yellow lines of this wavelength may have skewed the average, and thus affected the result of the rightmost peak's energy shift.

B. Observation of Patterns with Polarized Filters

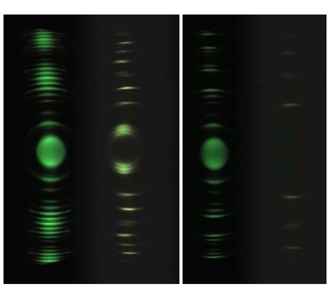

FIG. 2. Spectral Lines without and with Pi Polarization

TABLE III. Yellow Line: 579.07 nm

Expected Energy Shift $[\mu_B B]$	Measured Energy Shift $[\mu_B B]$	Measured Frequency Shift $[\mu_B B \times 10^{33} s^{-1}]$	Initial m_J	Final m_J
-1	-1.080	-1.630	0, -1, -2	1, 0, -1
0	0	0	1, 0, -1	1, 0, -1
1	1.150	1.736	2, 1, 0	1, 0, -1

As can be seen in figure 2, only the lines closest to the center of the patterns are preserved. For the yellow lines they consist of two series with one being normal and the other being partially normal and partially anomalous Zeeman effect. The anomalous lines end up splitting into three, which is preserved through the Pi-polarized filter. The normal Zeeman effect retains its singular peak through the Pi-polarized filter.

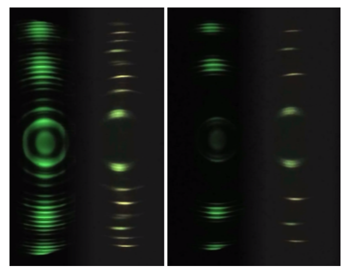

FIG. 3. Spectral Lines without and with Sigma Polarization

With the Sigma-polarizing filter in the above pictures, the middle lines are then blocked, with the side lines being the only lines showing up. For the green lines, this leaves three lines on each side, and for the yellow lines, there are only a single set of lines for the normal Zeeman effect, and the partial Zeeman effect's lines should be partially split, though this is difficult to resolve by eye.

V. DISCUSSION OF MIRROR SEPARATION

With the mirror separation used in this experiment of $1.7mm$, should this be changed to $1.9mm$, the position in time of the peak split from the "main peak" would be shifted. This is due to the Free Spectral Range changing in frequency, but not in time. e.g., Repeating peaks of the same frequency would still be separated by roughly $0.0189s$ for the green lines, but because the free spectral range would change from $\nu_{FSR} = c \div (2 \times 1.7mm)$ to $\nu_{FSR} = c \div (2 \times 1.9mm)$, or from $88.2GHz$ to $78.9GHz$, the conversion constant from time to frequency would change, and thus the location of split peaks would be increased in distance.