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PHYS375, fall 2009

Section 0301 – Professor Anlage

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# Lab 4

# Michelson Interferometer

# Lab 4 - Michelson Interferometer

Used ~~2~~ a diverging lens to expand the laser beam source (beam expander).

Aligned 2 spots on screen so they completely overlap.

Move $M_2$ to center the interference pattern in the spot. This way when the photo-detector replaces the screen and $M_1$ is translated the chip is completely in the light at some points and completely in the dark at others

data taken over 8 seconds and stored in sheet 1 of lab4.xls

## Sodium Light

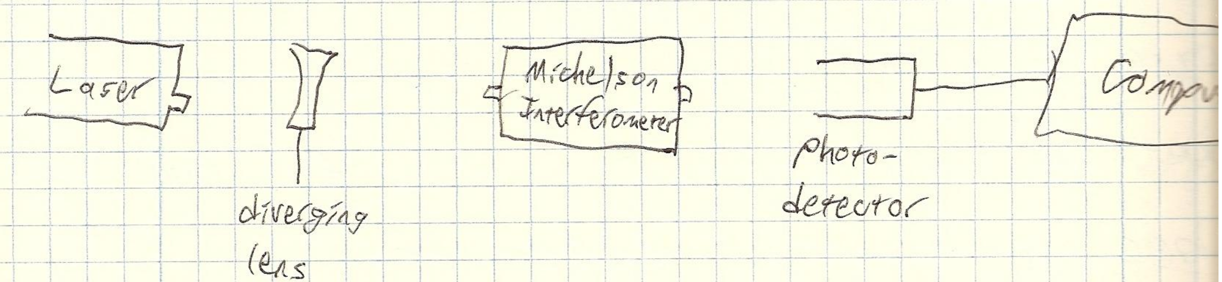
- set up laser and adjusted $M_2$ to center the interference pattern with the spot on the screen, then the Sodium Light is put in place & $M_2$ is <u>very</u> minorly adjusted to see the interference pattern.
- the iris is used to ~~align~~ align the Sodium Light into the Michelson Interferometer
- took 5 mins of data
- data stored in sheet 2 of lab4.xls
- same setup for 20min stored in sodium_run2.txt

# Sodium Light Improvements

- set up the same way as on page 36 but added converging lens between sodium light and iris, also because there is a converging lens at the exit of the interferometer, positioned the photo-detector at what appeared to be the focal point.
- took ~~25~~ mins of data and stored
  ~40 mins

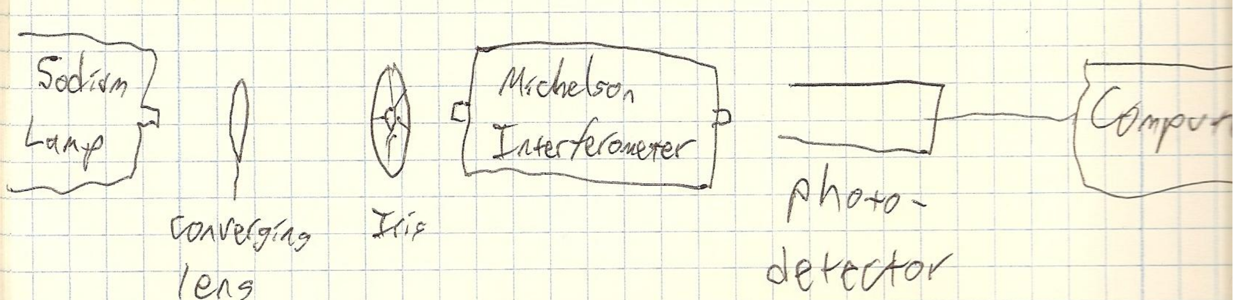
  it in sodium_run3.txt

## Laser Setup




## Sodium Setup


## Improved Sodium Setup



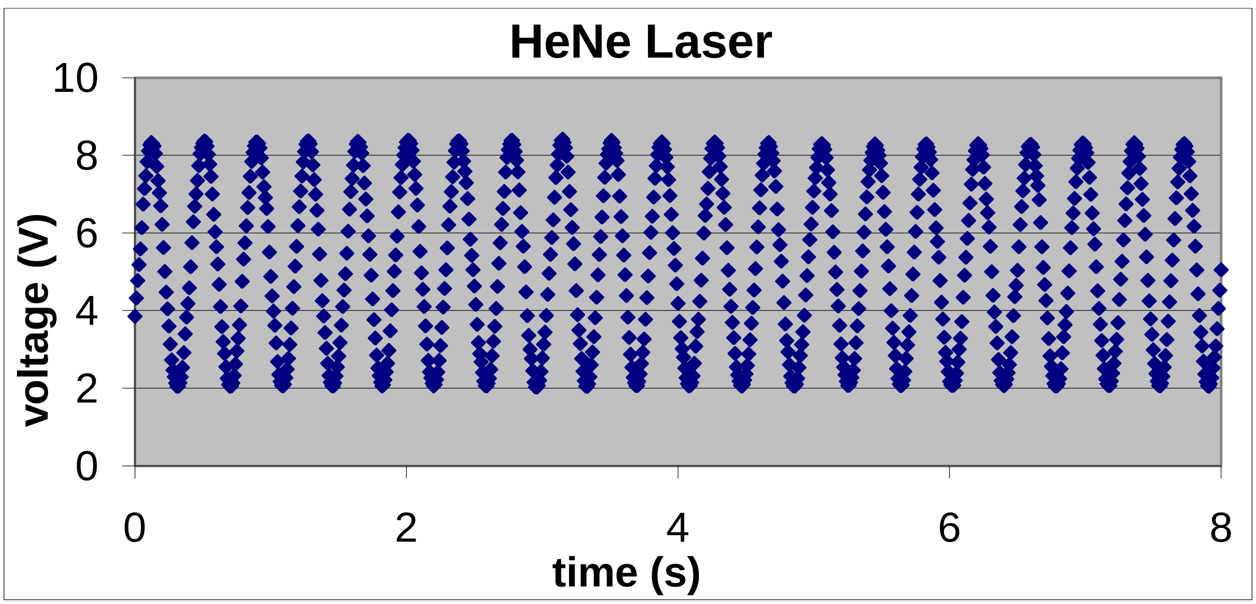
# Record of Experiment

- Actual notes from lab notebook shown on previous 4 pages.

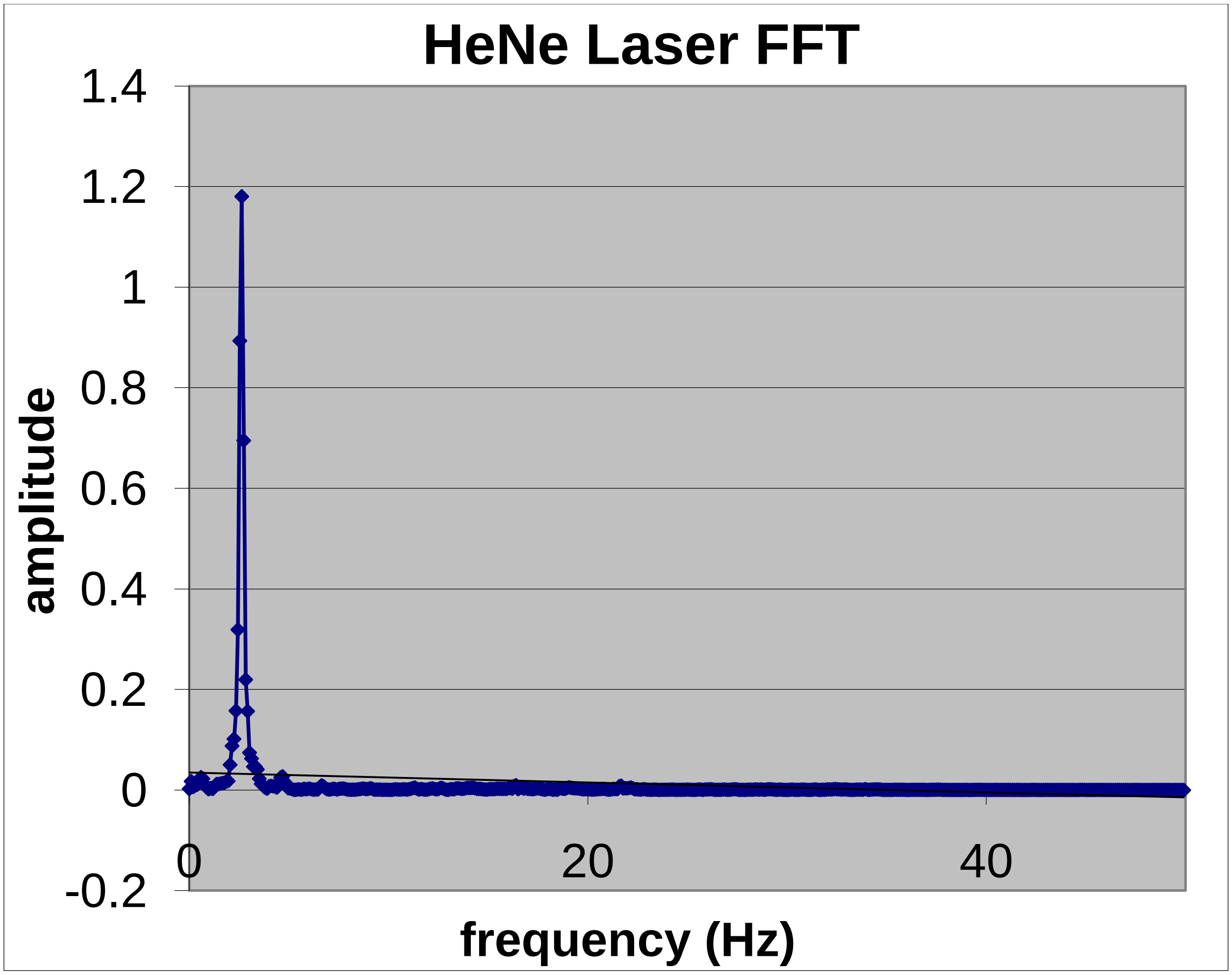
# Data Analysis

**Calibration with HeNe Laser**

- Below is a plot of the data taken with the HeNe laser light injected into the Michelson interferometer. Mirror 1 (M1) inside the Michelson interferometer is being translated at a constant speed by a motor. These data are used to find the speed of M1 which will be used in the Sodium Light section.




- To easily discern the frequency of the oscillations a Fast Fourier Transform (FFT) of the data above was done using LoggerPro and is shown below. The frequency was taken to be the data point with the highest amplitude (2.64 Hz), and the error in this was taken to be the full width at half maximum of the peak (0.22 Hz). This is random error most likely due to slight changes in the light that the laser is putting out.




This frequency of fringes (2.64+-0.22 Hz) can be used to find the speed of M1. This is shown below where *speed* is the speed of M1, $v$ is the frequency of fringes, and λ is the wavelength of the HeNe laser light. The speed of M1 is found to be **841 nm/s**.

$$speed = \frac{v\lambda}{2}$$

$$speed = \frac{(2.64\ \mathrm{Hz})(638.2\ nm)}{2}$$

$$speed = 841\ nm/s$$

The error in the frequency of fringes propagates to the speed of M1 as shown below. The error in the wavelength of the laser is taken to be zero. The error in the speed of M1 was found to be 70 nm/s.

$$\sigma_{speed}{}^2 = (\sigma_v \frac{\partial speed}{\partial v})^2$$

$$\sigma_{speed} = \frac{\sigma_v \lambda}{2}$$

$$\sigma_{speed} = \frac{(0.22\ Hz)(638.2\ \text{nm})}{2}$$

$$\sigma_{speed} = 70\ nm/s$$

In the lab handout, an estimation for the speed of M1 is given (found from the formula below). This is used to check the plausibility of the answer achieved above (note that the answer found is well within the error bar of the experimental answer found above). The answer found experimentally is used in the Sodium section (not the answer below).

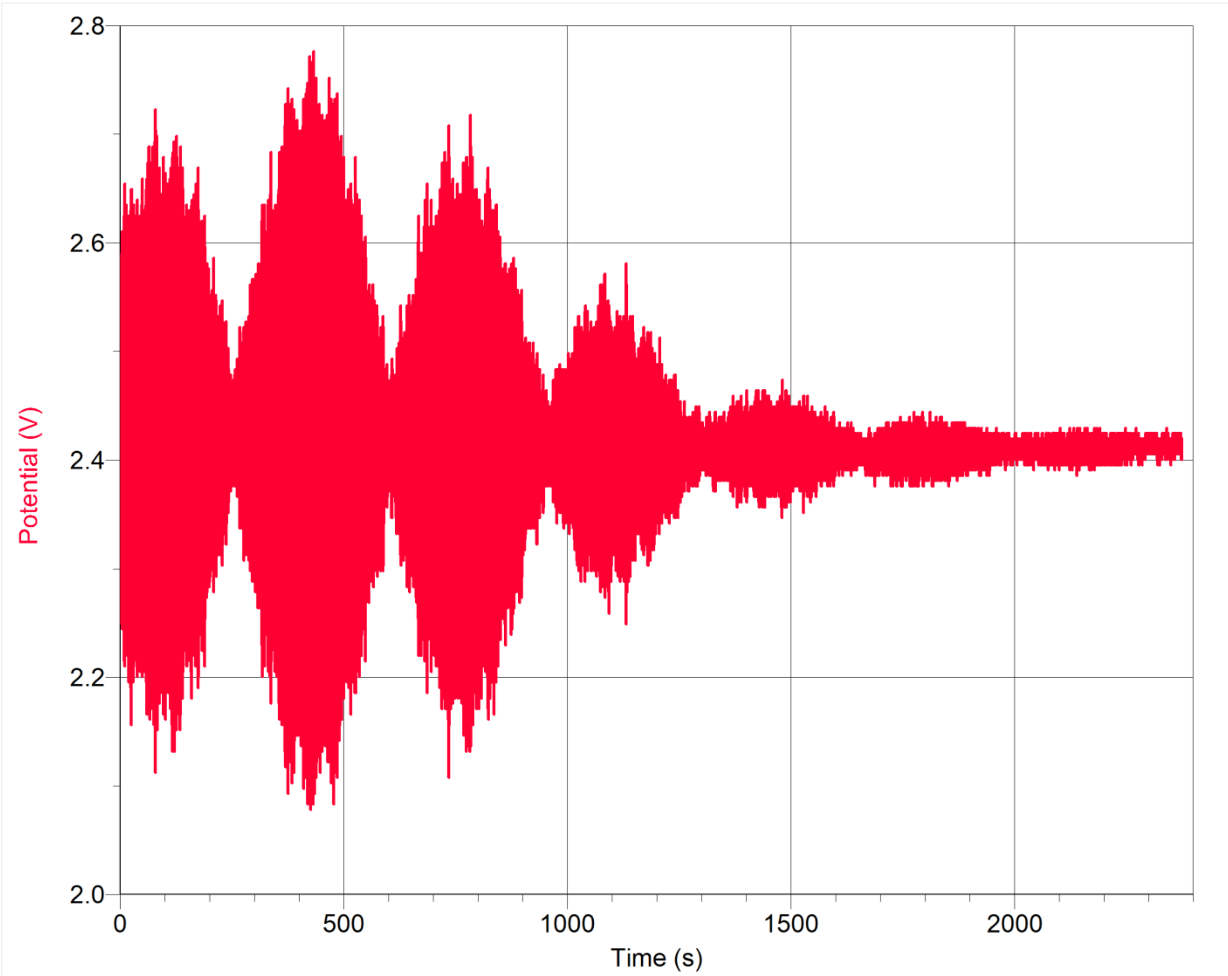
$$speed = \frac{(500\ \mu m/rev)(0.5rpm)}{(reduction\ factor)}$$

$$speed = \frac{(500\ \mu m/rev)(\frac{0.5}{60}\ rev/s)}{(5)}$$

$$speed = 833\ nm/s$$

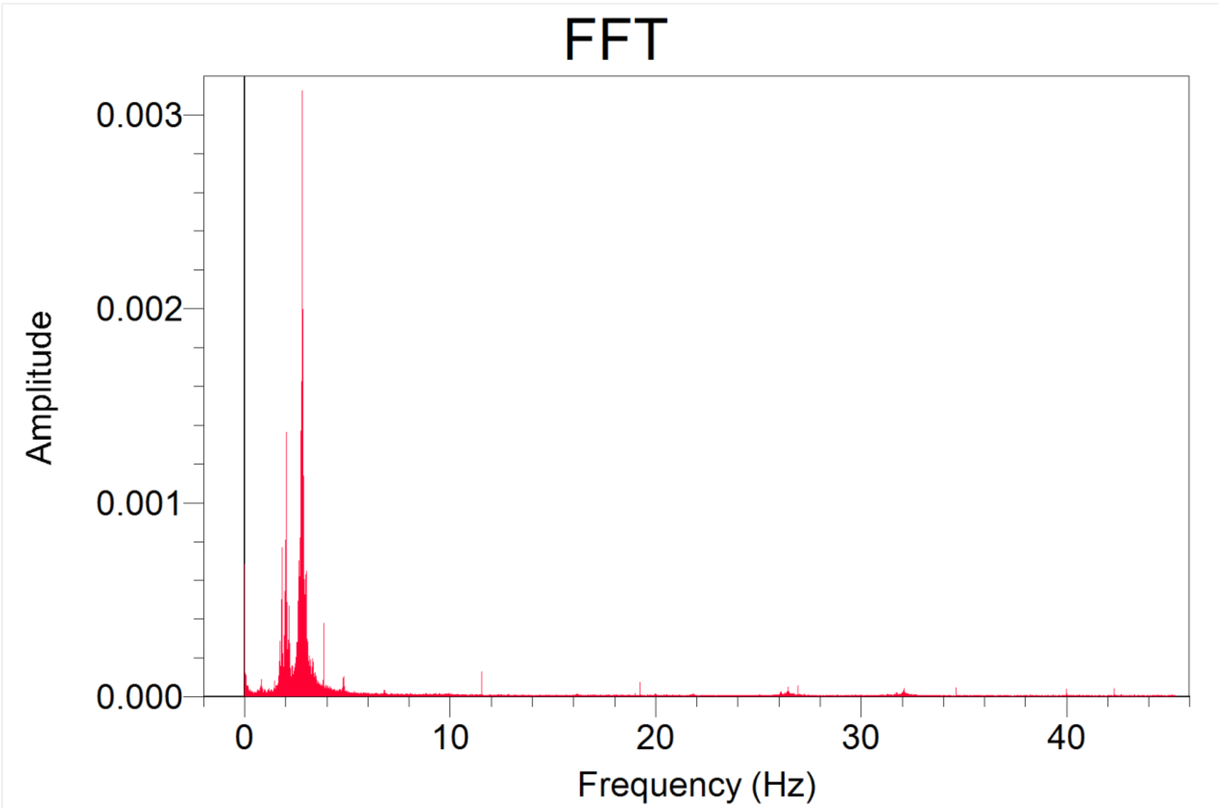
**Sodium Light**

- Below is a plot of the data taken with the sodium light injected into the Michelson interferometer. Mirror 1 (M1) inside the Michelson interferometer is being translated at 841 +- 70 nm/s (as found in the Calibration section). There is a lot of information in this plot. There is a fast oscillation (not visible in this plot but shown and discussed more later), an envelope oscillation, and an overall decay in amplitude.

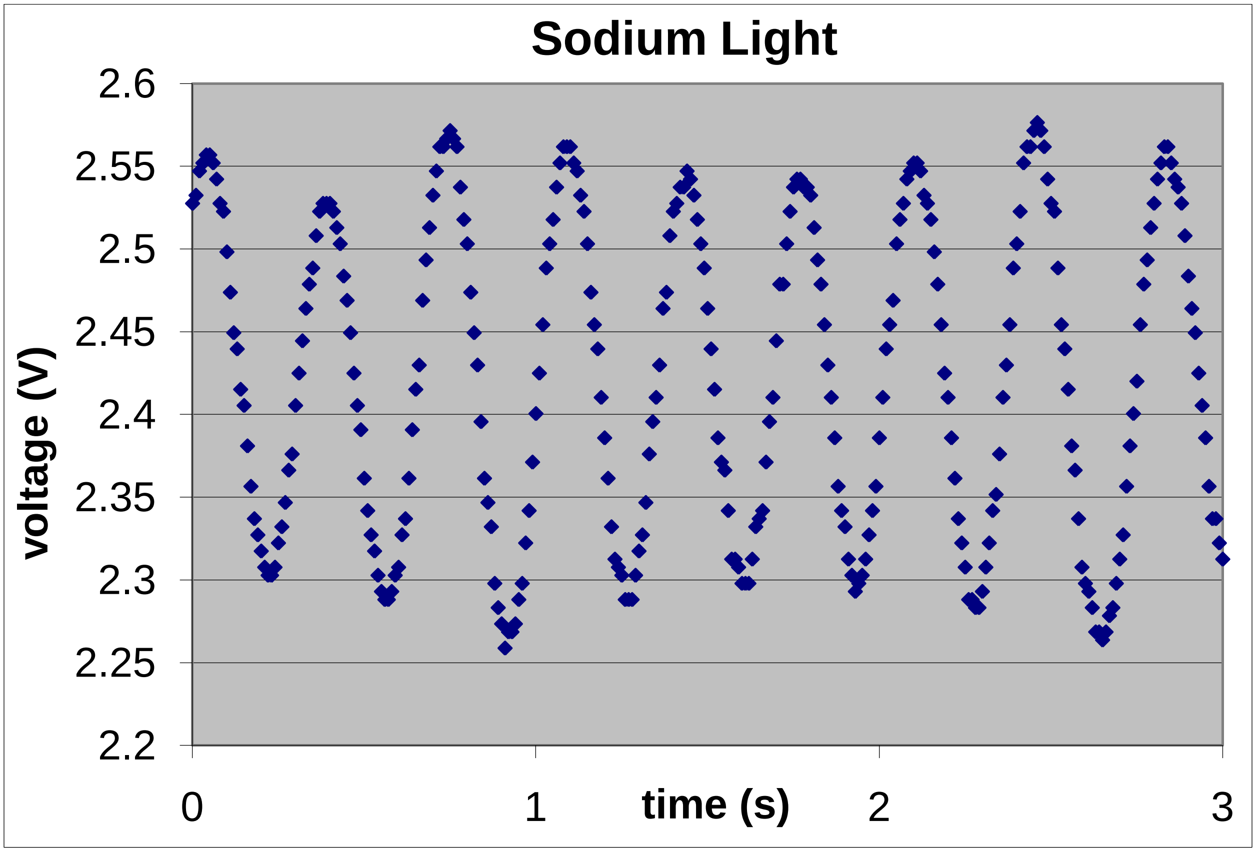



- The period of the envelope oscillation was taken to be the average of the distances between peaks for the first 4 peaks. This was found to be 343 seconds which gives a frequency of $v_{envelope}$ = 2.915 mHz. The error in the determination of each peak was 6 seconds. The propagation of this error to the error in $v_{envelope}$ is direct since $v_{envelope}$ is an average of the values with this error. The error in $v_{envelope}$ is 0.167 Hz (1/[6 seconds]).

- An FFT of the above data is taken and shown in the plot below. The large spike corresponds to the frequency of the fast oscillation in the data above. We will call it $v_{fast}$, and its significance will be discussed later. The error in $v_{fast}$ was taken to be the full width at half maximum of the peak. $v_{fast}$ = 2.812 +- 0.068 Hz.



- The FFT can be trusted because there are enough data points to discern a sinusoidal oscillation in each period. This is shown by the plot below which is just zooming in on the original data at the indicated time interval.




- Ignoring the overall decay in amplitude, the first graph in the section exhibits a beat pattern. It therefore obeys the following equation.

$$\sin(2\pi f_1 t) + \sin(2\pi f_2 t) = 2\cos\left(2\pi \frac{f_1 - f_2}{2} t\right) \sin\left(2\pi \frac{f_1 + f_2}{2} t\right)$$

- Above we have solved for the frequency of the sine and cosine (envelope) on the right hand side. These frequencies are $v_{envelope}$ and $v_{fast}$ respectively. This leads to the equations below which are used to solve for $f_1$ and $f_2$.

$$v_{fast} = 2.812 \text{ Hz} = \frac{f_1 + f_2}{2}$$

$$v_{envelope} = 2.915 \text{ mHz} = \frac{f_1 - f_2}{2}$$

$$f_1 = 2.815\ Hz$$

$$f_2 = 2.809\ Hz$$

- Using these frequencies to get the wavelengths of light in the sodium doublet is straight forward according to the following formula which uses the speed of the mirror M1 from the Calibration section.

$$\lambda = \frac{2(\text{speed})}{\text{f}}$$

- This gives values of 597.9 nm for $\lambda_1$ and 599.1 nm for $\lambda_2$.
- The error in $v_{envelope}$, $v_{fast}$, and the speed of M1 is propagated to $\lambda_1$ and $\lambda_2$ as shown below.

$$\sigma_{f_1}{}^2 = (\frac{\partial f_1}{\partial v_{fast}}\sigma_{v_{fast}})^2 + (\frac{\partial f_1}{\partial v_{envelope}}\sigma_{v_{envelope}})^2$$

$$\sigma_{f_2}{}^2 = (\frac{\partial f_2}{\partial v_{fast}}\sigma_{v_{fast}})^2 + (\frac{\partial f_2}{\partial v_{envelope}}\sigma_{v_{envelope}})^2 = \sigma_{f_1}{}^2$$

$$\sigma_{f_1} = \sigma_{f_2} = \sqrt{(\frac{1}{2}\sigma_{v_{fast}})^2 + (\frac{1}{2}\sigma_{v_{envelope}})^2}$$

$$\sigma_{f_1} = \sigma_{f_2} = 0.090\ Hz$$

$$\sigma_{\lambda 1}{}^2 = (\frac{\partial \lambda 1}{\partial speed}\sigma_{speed})^2 + (\frac{\partial \lambda 1}{\partial f_1}\sigma_{f_1})^2$$

$$\sigma_{\lambda 1} = \sqrt{(\frac{2}{f_1}\sigma_{speed})^2 + (\frac{2(speed)}{f_1{}^2}\sigma_{f_1})^2}$$

$$\sigma_{\lambda 1} = 53.28 \text{ nm}$$

$$\sigma_{\lambda 2}{}^2 = (\frac{\partial \lambda 2}{\partial speed}\sigma_{speed})^2 + (\frac{\partial \lambda 2}{\partial f_2}\sigma_{f_2})^2$$

$$\sigma_{\lambda 2} = \sqrt{(\frac{2}{f_2}\sigma_{speed})^2 + (\frac{2(speed)}{f_2{}^2}\sigma_{f_2})^2}$$

$$\sigma_{\lambda 2} = 53.40 \text{ nm}$$

- The overall decay in amplitude in the first graph in this section gives the coherence length of the sodium source which is not perfectly monochromatic. The time from the maximum to the end of the plot (where there is not sinusoidal oscillation) can be used to estimate the coherence length of the lamp as shown below.

$$l_t = (speed)(t)$$

$$l_t = \left(841\frac{nm}{s}\right)(2500s - 400s)$$

$$l_t = 1.8\ mm$$

- This is a rough estimate because the uncertainty in when the plot is no longer sinusoidal has such a large error (300s). This error and the error in the speed of M1 propagate to the coherence length as shown below.

$$\sigma_{l_t}{}^2 = \left(\frac{\partial l_t}{\partial speed}\sigma_{speed}\right)^2 + \left(\frac{\partial l_t}{\partial t}\sigma_t\right)^2$$

$$\sigma_{l_t} = \sqrt{(t\sigma_{speed})^2 + ([speed]\sigma_t)^2}$$

$$\sigma_{l_t} = \sqrt{([2100s][70\ nm/s])^2 + \left(\left[841\frac{nm}{s}\right][300s]\right)^2}$$

$$\sigma_{l_t} = 0.3\ mm$$

# Discussion of Results

**Calibration with HeNe Laser**

- The speed of M1 was found to be 841 +- 70 nm/s. This agrees well with the value found from the lab manual.
    - The predominant source of error was the determination of the frequency of fringes. To improve the accuracy of this calculation, this frequency should be measured more accurately.
    - An improvement for this experiment would be running a few different trials to see if the FFT would return a sharper peak (less error in the frequency).

**Sodium Light**

- The sodium doublet was found to be at 597.9+-53.3 nm and 599.1+-53.4 nm. The predominant source of error was the determination of the speed of M1. This value should be determined more accurately to improve the determination of the sodium doublet.
    - The actual values of the sodium doublet (589 nm and 589.6 nm) are within the error bars of these calculations.
- The coherence length of the sodium lamp was found to be 1.8+-0.3 mm. The predominant source of error was the time but not by much. This error and the error in the speed were on the same order of magnitude. Either value could be determined more accurately to improve the determination of the coherence length of the sodium lamp.