Michelson Interferometer

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A three-part experiment was conducted using Michelson interferometry. In part one a HeNe laser beam ($\lambda = 632.8\,\text{nm}$) was aimed through the Michelson apparatus where the path length difference of 2000 fringes was measured. This yielded $\lambda_{avg} = 640.0 \pm 8.1\,\text{nm}$, which differed $0.9\,\sigma$ from the accepted value. Also, a green laser pointer ($\lambda = 532\,\text{nm}$) was aimed through the apparatus where the path length difference of 500 fringes was measured. This yielded $\lambda = 532.0 \pm 9.6\,\text{nm}$. In part two a Sodium I lamp ($\Delta\lambda = 0.5974\,\text{nm}$) was projected through the same apparatus to yield $\Delta\lambda = 0.5971 \pm 0.0004\,\text{nm}$, which differed $0.8\,\sigma$ from the accepted value. In part three a white light source encompassing the visible spectrum was shown through the same apparatus to find white light fringes (zero path length for the apparatus), which was located at $8.0905 \pm 0.0005\,\text{mm}$.

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I. INTRODUCTION

Michelson interferometry works by splitting a light beam into two paths. The paths remain close together but have two different path lengths. The beams are then brought back together. The result is that an interference pattern is formed that can be used to measure the wavelength of the light. A representative schematic of the Michelson apparatus is shown in Figure 1 (below).

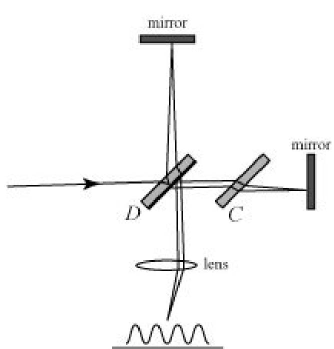

Figure 1: Michelson Schematic.[1]

The reconvergence of the beam paths creates a circular interference pattern (see Figure 2 below).

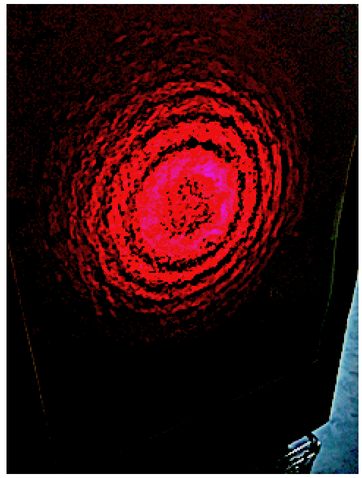

Figure 2: HeNe Laser Interference Pattern.

Part One–Lasers. By changing the distance of the translating mirror, (vertical path–see Figure 1 above), the rings of the interference pattern caused by a monochromatic light source will move either toward the center or away from the center. Counting the rings as they move in or out and obtaining the change in distance of the translating mirror will allow for a simple calculation of the wavelength of the light (see Equation 1 below).

$$\lambda_{HeNe} = \frac{2(d_f - d_0)}{n} \tag{1}$$

Part Two–Sodium Lamp. A mostly dichromatic light source (the sodium lamp used in this experiment is not technically dichromatic but behaves in this manner because the other wavelengths are extremely weak[2]) involves the constructive and destructive interference of both wavelengths. As the translating mirror distance is changed one of the two wavelengths will move to or away from the center of the ring pattern more quickly than the other wavelength. At certain distances the interference patterns will interfere in such a manner to generate a "wash-out" effect where rings are observed at minimum visibility. Obtaining an average of these positions (linear fit) will allow for the calculation of the difference between the two wavelengths (see Equation 2 below):

$$\Delta\lambda_{Na} = \frac{|\lambda_{avg}|^2}{2 \times d_{fit}} \tag{2}$$

$$|\lambda_{avg}|^2 \approx \lambda_1 \times \lambda_2 \qquad \textbf{Source:}\ \text{PHYS 4010 Michelson Task Sheet} \tag{3}$$

A convenient property for this experiment is that the two strongest wavelengths of the sodium light are fairly close ($588.9950\,\text{nm}$ and $589.5924\,\text{nm}$)[2], allowing for a usable approximation of $|\lambda_{avg}|^2$ (see Equation 3 above).

Part Three–Whitelight Source. White light has a large number of wavelengths with many differences in phase, that when shown through the Michelson apparatus will cause overlaps between maxima and minima of these phases. As a result the fringes seen in the other experiments will disappear until the zero path length is reached.[3]

II. EQUIPMENT

- (1x) Michelson Interferometer
- (1x) Uniphase Model 1135p Helium Neon Laser ($\lambda = 632.8\,\text{nm}$) with power supply
- (1x) Sodium Lamp ($\lambda_{avg} = 589.2\,\text{nm}$)
- (1x) White Light
- (1x) Laser Mount
- (1x) Divergence Lens
- (2x) Mirrors

III. EXPERIMENTAL PROCEDURE

The setup for all three parts essentially consists of a light source aligned with the Michelson apparatus light path input. Depending upon the mounting configuration chosen, the light source beam may need to be channeled with mirrors and lenses. In the case of the HeNe laser, a divergence lens was used to broadened the beam input into the Michelson apparatus. A piece of semi-transparent tape was used to cover the white light source to reduce the light intensity (see Figure 3 below).

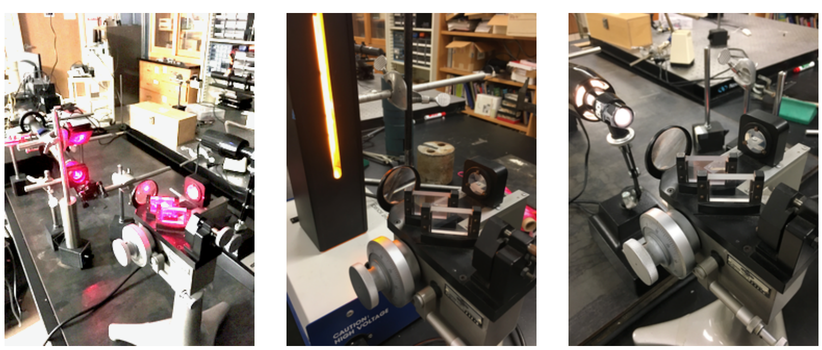

Figure 3: Michelseon Setup. *Left:* The HeNe laser is in the upper left pointing toward lower right. The beam is guided through a series of mirrors to bring it to the level of the Michelson apparatus in the lower left corner. *Middle:* The sodium lamp required no beam guidance. *Right:* The white light source required manipulation to align the light path with the apparatus.

Part One–Lasers. The HeNe laser was aligned to the center of the Michelson input path so that the beam hit the approximate center of the mirrors on both arms. A box with white paper was set on the output path in order to visually observe the fringes. The translating mirror was arbitrarily set to 4.00 mm (a reference easy to subtract for path length difference) to begin the experiment. The fine-tune knob was used to advance the distance, causing the fringes to move toward the center of the ring pattern (see Figure 2 above). The fringes were counted as they passed a mark placed on the paper.

After 2000 fringes were counted, the translating mirror was advanced until a range could be determined for the zero path length. The zero path length occurred in the range where the fringes changed from moving toward the center to moving outward from the center.

Similarly the green laser was aligned with the Michelson input path. The translating mirror was set to 4.00 mm to begin the experiment. In this case only 500 fringes were counted.

Part Two–Sodium Lamp. Initial alignment was performed with the HeNe laser. Due to the very broad dispersion of light from the sodium lamp, no additional steps were needed for alignment. For observation of the light, one eye was covered to prevent parallax, and a blinder was used with the other eye to prevent stray sodium light from entering. Eye fatigue was a factor, but since counting was not involved, the fatigue was more manageable. Initially the translating mirror was set to 0.00 mm; however, while the rings were clearly visible, the contrast was not sufficient for accurate data collection. Data could not be taken until the translating mirror was advanced to 2.00 mm. Similarly the washouts became less distinguishable (more dark) as the translating mirror approached zero path length above 7.00 mm.

Part Three–Whitelight Source. The Michelson was calibrated by centering the Michelson with the HeNe laser source with the vertical distance set to 7.50 mm (about 0.50 mm lower than the estimated zero path length). Then the HeNe laser was set aside and the white light source was applied. The white light source had a focused beam, requiring some alignment of the source to center the beam onto the Michelson input path and mirrors. The search for a precise zero path length measurement was conducted by slowly advancing the Michelson with the fine-tune knob from 7.50 mm. Even with alignment of the Michelson with the HeNe laser, the white light fringes appeared very narrow when initially discovered. Fine tuning of the Michelson mirrors expanded the fringes so that they were more discernible.

IV. ANALYSIS

Part One–Lasers. Measurements of HeNe laser fringe movements were taken at 2000 fringes. Calculations were based on Equation 1 (above). The accepted value for the HeNe laser ($\lambda = 632.8\,\text{nm}$) fell inside the calculated uncertainty window $\lambda = 640.0 \pm 8.1\,\text{nm}$. At 500 fringes the green laser produced $\lambda = 532.0 \pm 9.6\,\text{nm}$, centered at the value specified on the laser body.

During this part of the experiment, it was noted that manually counting the fringes produced heavy eye fatigue in a very short amount of time, even with pauses. For this reason the error numbers for "n" are fairly high for both lasers ($\pm 1.0\%$). In addition to the high counting error, the acme screw used to translate the mirror also has error. This error is difficult to predict, but estimated $\pm 0.005\,\text{mm}$ over $0.640\,\text{mm}$ (HeNe laser) and $\pm 0.002\,\text{mm}$ over $0.133\,\text{mm}$ (green laser). These uncertainties would include the original machining tolerance plus wear from periodic use. Consideration may be given to the thermal expansion of the metal (aluminum); however, it is believed that the temperature of the environment remained fairly constant during the experiment.

Part Two–Sodium Lamp. Measurements of sodium lamp washouts were taken for 19 points (see Table 1 below). The uncertainty was larger at the beginning of the data set due to difficulty in discerning fringe contrasts from wash-outs, because the contrasts were not distinctive (the spacing was narrow but rings were clearly visible). The opposite affect took place as the zero path length was approached. The washout locations were not as subdued and more difficult to discern from locations with higher contrast.

The locations were determined by noting the distances where each wash-out phenomenon began and ended. The best locations within these ranges could not be discerned. The midpoints of the ranges were calculated and uncertainties determined based on the range boundaries. This calculation assumes that the best washout location existed at the midpoints. Further investigation would need to be undertaken to determine if the midpoints are the best locations.

Table 1: Sodium Lamp Wash-outs

n	Position	n	Position
1	2.1225 ± 0.0025 nm	11	5.039 ± 0.001 nm
2	2.4125 ± 0.0025 nm	12	5.329 ± 0.001 nm
3	2.7125 ± 0.0025 nm	13	5.615 ± 0.001 nm
4	3.0125 ± 0.0025 nm	14	5.911 ± 0.001 nm
5	3.2975 ± 0.0025 nm	15	6.201 ± 0.001 nm
6	3.5875 ± 0.0025 nm	16	6.497 ± 0.001 nm
7	3.8775 ± 0.0025 nm	17	6.783 ± 0.001 nm
8	4.1675 ± 0.0025 nm	18	7.0625 ± 0.0025 nm
9	4.4575 ± 0.0025 nm	19	7.3625 ± 0.0025 nm
10	4.7475 ± 0.0025 nm		

Three fit lines were produced from the data in Table 1 (above). The fit lines represent the uncertainty at lower and upper boundaries, and the middle points (see Figure 4 below).

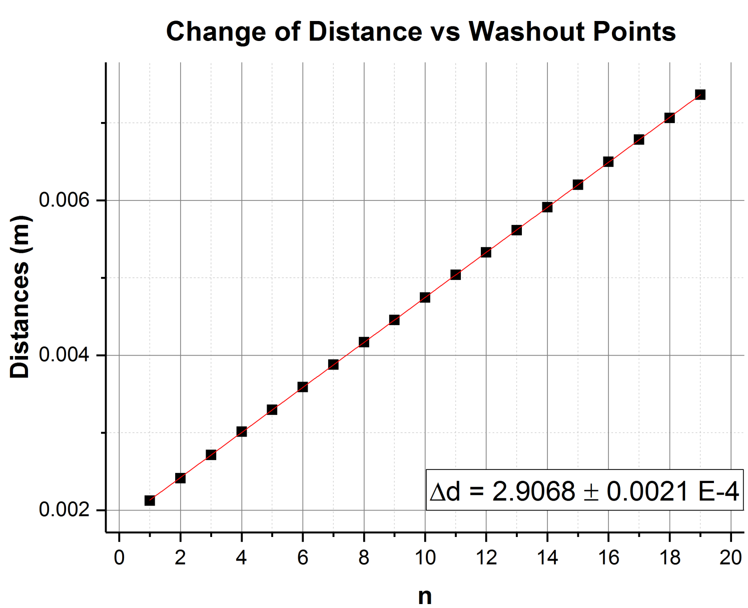

Figure 4: Fit Line. Change in translating mirror position from initial reference at each washout point

The fit line yielded $\Delta\lambda_m = 0.5971 \pm 0.0004\,\text{nm}$. The uncertainty range encompassed the accepted value $\Delta\lambda = 0.5974\,\text{nm}$ with a difference of $0.8\,\sigma_m$.

Part Three–Whitelight Source. Attempts were made to locate the zero path length of the Michelson apparatus with each of the three light sources. The HeNe laser produced a range between 7.95 mm and 8.10 mm. The sodium lamp produced a range between 7.985 mm and 8.005 mm. The white light source produced fringes that were initially located 8.088 mm and 8.094 mm. This was further narrowed to 8.0905 ± 0.0005 mm. The zero path length range produced by the sodium lamp was based on a single data point. This experiment would need to be conducted again to determine the data point's validity.

V. DISCUSSION

The big source of systematic error during for all three portions of the experiment was eye fatigue in counting laser fringes, causing missed counts. The use a photo sensor coupled with a small microcontroller to automatically perform the counting should remedy the missed counts. This will improve the accuracy and precision of the laser part of the experiment. The remainder of the experiment proceeded smoothly and produced expected results.

VI. REFERENCES

(1) skullsinthestars; *Measuring the Speed of Light*; blog posted at https://skullsinthestars.com/2008/03/21/relativity-measuring-the-speed-of-light/, accessed 7 Feb 2017.

(2) NIST; *Strong Lines of Sodium (Na)*; posted at http://physics.nist.gov/PhysRefData/Handbook/Tables/sodiumtable2.htm, accessed 10 Feb 2017.

(3) anonymous; *The Michelson Interferometer*; instructions posted at http://www.phys.vt.edu/~labs/phys3504/spring06/mich.pdf, accessed 9 Feb 2017.