Michelson Experiment Summary

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Outline

The History of Michelson Interferometer

- The Michelson interferometer is designed by Albert Michelson.
- Historically, it disproved the existence of the "luminiferous aether" and contributed to the discovery of relativity.
- Interferometers are used in:
    - Precision measurements
    - LIGO for detecting gravitational waves [1]

Interference of Light Waves

- The interference pattern depends on the phase difference:

$$\Delta\phi = 2\pi \frac{\Delta x}{\lambda}$$

- Intensity of interference:

$$I = I_0 \cos^2(\Delta\phi)$$

- Maximum interference: $\Delta\phi = 2\pi n$
- Minimum interference: $\Delta\phi = (2n + 1)\pi$

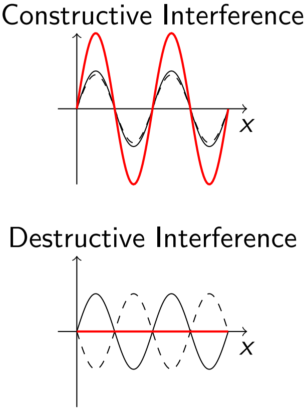


Figure: Solid/dash lines: individual waves. Red lines: resultant waves

Visibility of the Interference Pattern Measures how Resolved the Pattern is

- Visibility measures how well the pattern is resolved:

$$V = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}}$$

- Ideal case: $V = 1$
- Low visibility $\Rightarrow$ poor alignment or coherence issues

Piezoelectric Transducer Controls the Path Difference

- A piezoelectric transducer moves a mirror in response to voltage.
- This changes the path length Δx proportional to voltage.
- The wavelength of light is found using:

$$\lambda = 4\Delta V \times \frac{\Delta L}{V}$$

Michelson Interferometer Setup

- Light source: laser
- 50/50 beam splitter splits the light into two paths.
- One mirror is stationary, the other mounted on a piezoelectric transducer.
- Detector: photodiode (voltage output proportional to intensity).
- Signal generator applies a triangular voltage to move the mirror.

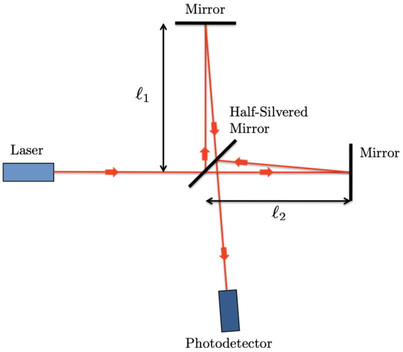


Figure: Schematic of the Michelson interferometer. Adapted from [2].

All the Data We Gathered

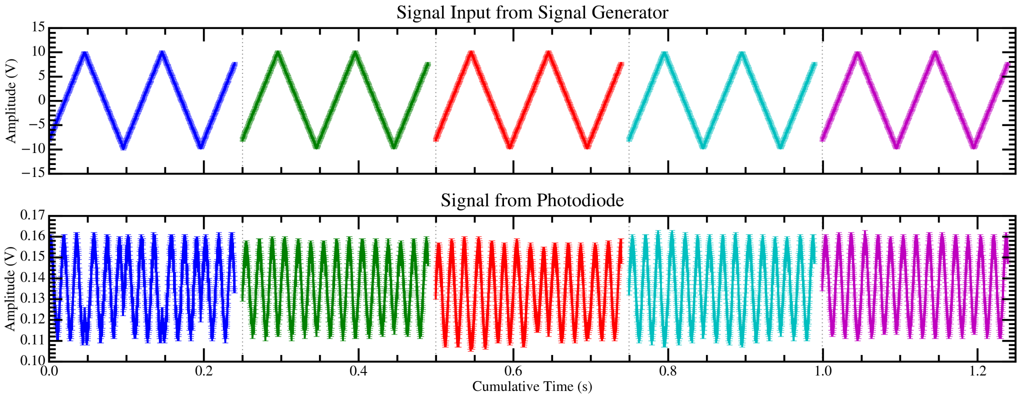


Figure: Total Data from oscilloscope. Error from the resolution of oscilloscope.

Raw Data from One Run

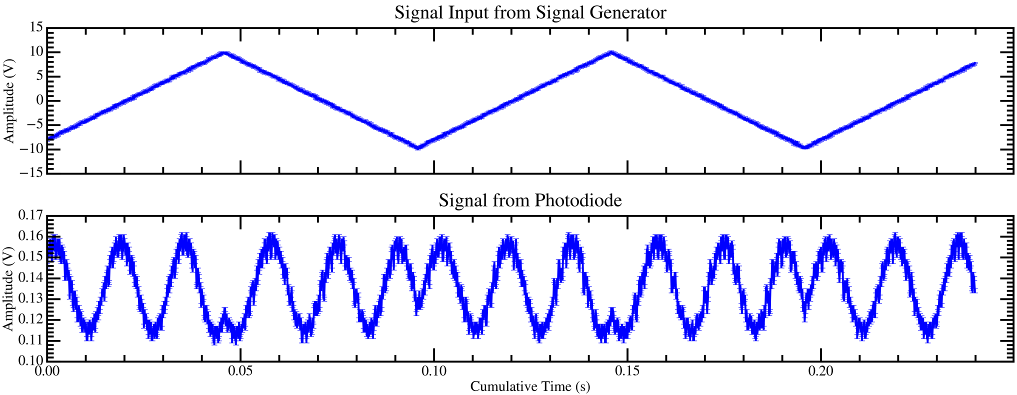
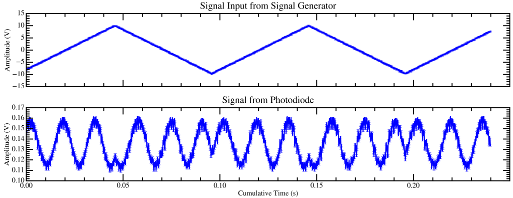


Figure: Raw Data from oscilloscope. Error from the resolution of oscilloscope.

Data Processing and Interference Pattern Visibility

- Voltage signals recorded from signal generator and photodiode.
- Used `findpeak` in `SciPy` to locate primary maxima and minima.
- Applied `KMeans` clustering (`SciKit-Learn`) to group voltage values.



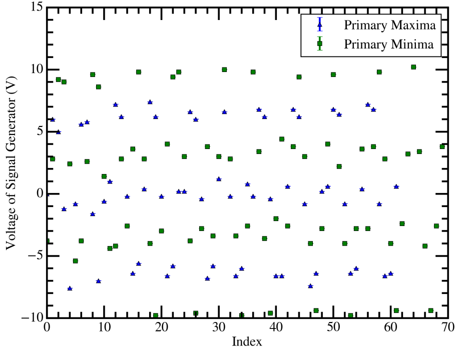


Figure: Voltage at primary maxima and minima.

Visibility 0.179 ± 0.001 Not Perfect but Significant

- Maximum voltage: (1.592 ± 0.002) V
- Minimum voltage: (1.110 ± 0.002) V
- Visibility:

$$V = 0.179 \pm 0.001$$

- Imperfect alignment likely lowered visibility.

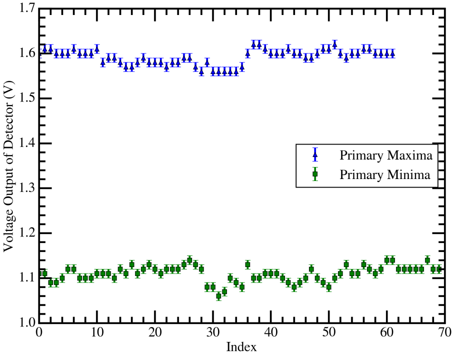


Figure: Voltage output of photodiode corresponding to maxima and minima.

Wavelength $601 \pm 37(\mathrm{sys}) \pm 10(\mathrm{stat})$nm Matches the Color of the Laser

- Measured voltage difference between peaks: (3.192 ± 0.055) V
- Calculated wavelength:

$$\lambda = 601 \pm 37(\mathrm{sys}) \pm 10(\mathrm{stat}) \text{ nm}$$

- Matches expected wavelength of the orange laser.

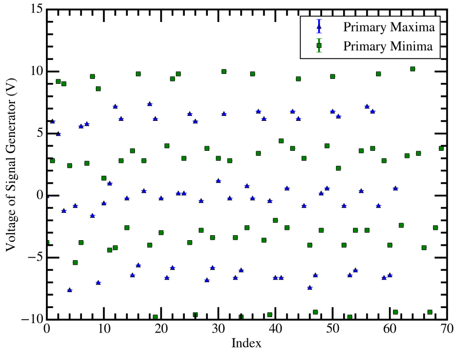


Figure: Voltage at primary maxima and minima.

Uncertainty Dominated by Calibration of the Piezoelectric

- **Systematic error**: Calibration of the piezoelectric device

$$\delta\lambda = 37 \text{ nm}$$

- **Statistical error**: Peak detection noise

$$\delta\lambda = 10 \text{ nm}$$

Conclusion and Future Improvements

- Successfully measured the wavelength of an orange laser:

$$601 \pm 37(\text{sys}) \pm 10(\text{stat}) \text{ nm}$$

- Demonstrated interference and wave nature of light.
- Future improvements:
    - Improve mirror alignment for higher visibility.
    - Use a more precise piezoelectric transducer.
    - Implement automated feedback to stabilize fringes.

Acknowledgments

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References I

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