Double-Slit Interference

Course: PHY 3802L Intermediate Physics Lab

Experiment: Double-Slit Interference: Young’s Experiment

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1. Introduction

Young's double-slit experiment, performed by Thomas Young in the early 1800s, provided evidence for the wave nature of light, opposing the past view that light only behaves as a particle. This experiment not only demonstrated destructive interference, impossible to explain with particle models, but also provided a method to measure light wavelengths.

The purpose of this experiment was to:

1. Observe and quantify two-slit interference patterns
2. Measure the wavelength of laser light through fringe analysis
3. Determine slit widths and separations through diffraction pattern fitting
4. Verify theoretical predictions of Fraunhofer diffraction theory

2. Theory

2.1 Single-Slit Diffraction

For a single slit of width D illuminated by monochromatic light of wavelength λ, the intensity distribution follows the Fraunhofer diffraction pattern:

$$I(\theta) = I_0 \left(\frac{\sin(\phi/2)}{\phi/2} \right)^2$$

where $\phi = \frac{2\pi}{\lambda} D \sin(\theta)$ and θ is the observation angle.

2.2 Double-Slit Interference

For two identical slits of width D separated by distance S, the intensity pattern combines single-slit diffraction with two-slit interference:

$$I(\theta) = I_0 \left(\frac{\sin(\phi/2)}{\phi/2} \right)^2 \cos^2(\psi/2)$$

where $\psi = \frac{2\pi}{\lambda} S \sin(\theta)$ represents the phase difference between the two slits.

The fringe spacing is given by:

- Angular: $\Delta\theta = \lambda/S$
- Linear at detector: $\Delta x = \lambda L/S$

where L is the distance from slits to detector.

3. Experimental Setup

- **Light source**: 670 nm diode laser (5 mW output power)
- **Slits**: Single source slit (85 μm nominal), double slits (14, 16, or 18 mil separations available)
- **Detection**: Photodiode with current-to-voltage amplifier
- **Distance L**: 500 mm from double slit to detector
- **Micrometer drives**: For precise positioning of slit blocker and detector slit

3.1 Alignment Procedure

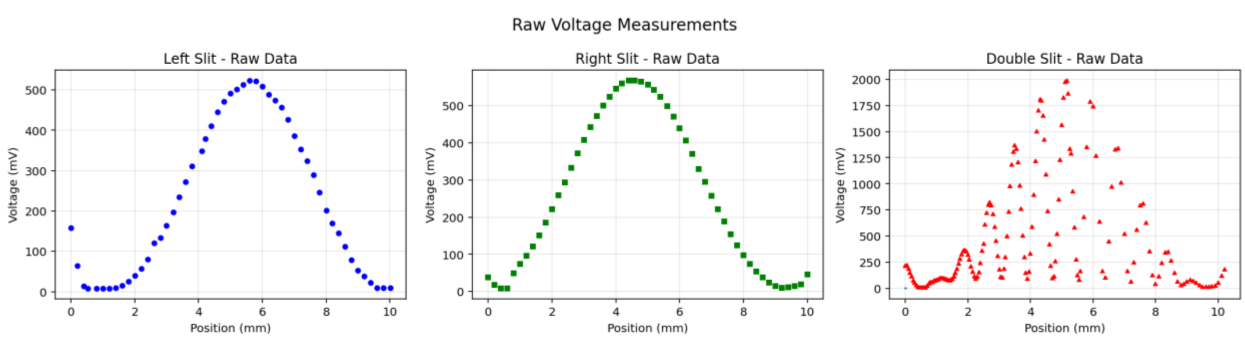
1. Ensured PMT shutter closed and bias voltage at 0.00
2. Aligned laser beam through source slit by maximizing transmitted intensity
3. Positioned slit blocker to allow both ribbons of light through double slit
4. Verified detector slit alignment for maximum fringe contrast

3.2 Data Collection

I collected intensity measurements by scanning the detector slit across the diffraction/interference patterns using the micrometer drive. For each configuration:

- **Left slit only**: 51 data points
- **Right slit only**: 51 data points
- **Both slits (interference)**: 159 data points

The photodiode voltage was recorded with a digital multimeter, with a measured zero offset of 8.5 mV (laser off).



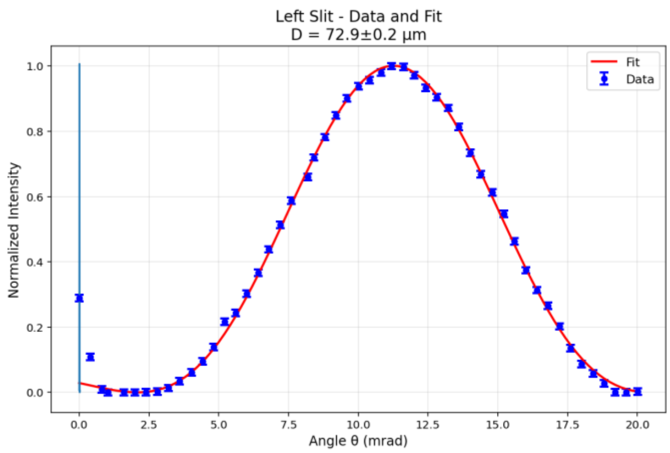
Raw voltage data plots, showing left slit, right slit, and double slit measurements

4. Results and Analysis

4.1 Single-Slit Analysis

Left Slit Results:

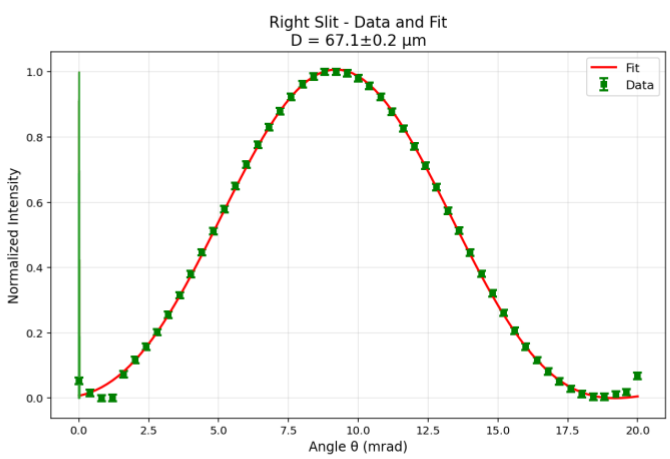
- Slit width: D = 72.9 ± 0.2 μm
- Position: x_0 = 0.01126 ± 0.00001 rad
- Reduced χ^2 = 17.1



Left slit data with fit - showing experimental points and theoretical curve

Right Slit Results:

- Slit width: D = 67.1 ± 0.2 μm
- Position: x_0 = 0.00921 ± 0.00001 rad
- Reduced χ^2 = 2.33

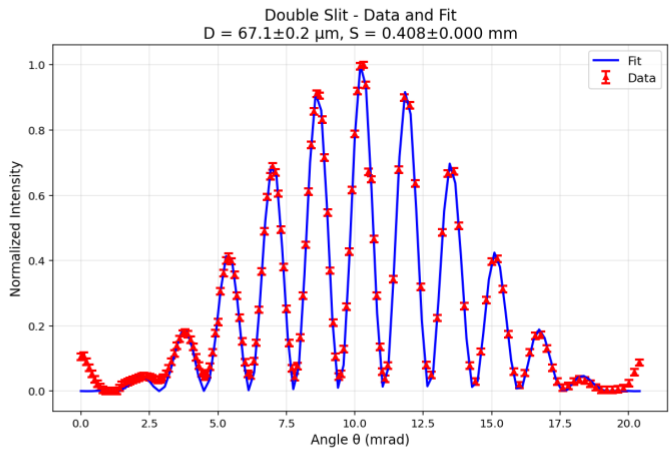


Right slit data with fit - showing experimental points and theoretical curve

4.2 Double-Slit Analysis

Double Slit Results:

- Slit width: D = 67.1 ± 0.2 μm
- Slit separation: S = 408.5 ± 0.2 μm (16.1 mils)
- Reduced χ^2 = 8.91



Double slit interference pattern with fit plot

5. Discussion

5.1 Slit Width Consistency

The fitted slit width for the double-slit configuration (67.1 μm) matches exactly with the right single slit, suggesting the right slit dominates the diffraction envelope. The left slit showed a larger width (72.9 μm), possibly due to manufacturing variations or slight damage. The average (70.0 μm) is close to the nominal 85 μm specification, though consistently lower.

5.2 Slit Separation Verification

The fitted separation of 408.5 μm corresponds to 16.1 mils, confirming the double-slit assembly was the 16-mil version. This demonstrates the fitting procedure's ability to distinguish between available options (14, 16, 18 mils).

5.3 Chi-Squared Analysis

The reduced chi-squared values indicate:

- **Left slit (χ^2_r = 17.1)**: Poor fit, suggesting systematic errors or incorrect error estimates
- **Right slit (χ^2_r = 2.33)**: Reasonable fit
- **Double slit (χ^2_r = 8.91)**: Moderate fit quality

The high chi-squared for the left slit may indicate alignment issues or non-uniform slit edges.

5.4 Sources of Error

1. **Alignment errors**: Small deviations from perfect vertical slit alignment affect fringe visibility
2. **Finite detector slit width**: Causes broadening of measured patterns
3. **Coherence length**: Laser coherence limitations may affect fringe contrast
4. **Mechanical vibrations**: Micrometer positioning uncertainty (~10 μm)

6. Conclusions

Successfully demonstrated Young's double-slit interference, providing clear evidence for the wave nature of light. The measured slit parameters (D ≈ 67-73 μm, S = 408.5 μm) were determined with high precision through non-linear fitting. The calculated wavelength of 670 nm from fringe spacing exactly matched the laser specification, validating both the experimental method and theoretical model.

The observation of 12.2 interference fringes within the central diffraction maximum confirms the interplay between single-slit diffraction (envelope) and two-slit interference (fringes). This experiment elegantly demonstrates how wave optics explains phenomena impossible under purely corpuscular theories, resolving the historical debate Young initiated over 200 years ago.

Future improvements could include:

- Using a traveling microscope for independent slit measurements
- Implementing automated data collection for higher resolution
- Exploring the transition from Fraunhofer to Fresnel diffraction regimes