Optics: Interference Patterns and Analysis

Computational Science Templates

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1 Introduction

Interference phenomena demonstrate the wave nature of light through the superposition of coherent waves. This analysis explores Young's double-slit experiment, multiple-beam interference, Michelson interferometry, and Fabry-Pérot cavities, examining both intensity patterns and their applications in metrology and spectroscopy.

2 Mathematical Framework

2.1 Two-Beam Interference

For two coherent beams with amplitudes E_1 and E_2 and phase difference δ:

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\delta \tag{1}$$

2.2 Double-Slit with Diffraction

The intensity pattern for double-slit interference with single-slit diffraction:

$$I(\theta) = I_0 \left(\frac{\sin\beta}{\beta}\right)^2 \cos^2\alpha \tag{2}$$

where $\alpha = \frac{\pi d \sin\theta}{\lambda}$ (interference) and $\beta = \frac{\pi a \sin\theta}{\lambda}$ (diffraction).

2.3 Multiple-Beam Interference

For N slits (grating), the intensity is:

$$I = I_0 \left(\frac{\sin\beta}{\beta}\right)^2 \left(\frac{\sin N\alpha}{\sin\alpha}\right)^2 \tag{3}$$

2.4 Fabry-Pérot Interferometer

Transmission of a Fabry-Pérot cavity:

$$T = \frac{1}{1 + F\sin^2(\delta/2)} \tag{4}$$

where $F = \frac{4R}{(1-R)^2}$ is the finesse coefficient and $\delta = \frac{4\pi n d \cos\theta}{\lambda}$.

3 Environment Setup

4 Young's Double-Slit Experiment

5 Multiple-Slit Interference (Diffraction Grating)

6 Michelson Interferometer

7 Fabry-Pérot Interferometer

8 Newton's Rings and Thin Film Interference

9 Coherence and Visibility

10 Results Summary

11 Statistical Summary

- **Wavelength**: $\lambda =$ **??** nm
- **Slit separation**: $d =$ **??** mm
- **Slit width**: $a =$ **??** μm
- **Screen distance**: $L =$ **??** m
- **Fringe spacing**: **??** mm
- **Fringes in central maximum**: $\approx$ **??**
- **Fabry-Pérot FSR**: **??** pm
- **Fabry-Pérot finesse** ($R = 0.98$): **??**
- **Resolving power**: **??** $\times 10^6$

12 Conclusion

Interference patterns provide crucial evidence for the wave nature of light and enable high-precision measurements. The double-slit pattern shows interference fringes modulated by a single-slit diffraction envelope. Multiple-slit gratings provide enhanced resolution proportional to the number of slits. Michelson interferometry enables nanometer-scale displacement measurements with applications in gravitational wave detection. Fabry-Pérot cavities achieve ultra-high spectral resolution with finesse values exceeding 1000, critical for laser spectroscopy and optical communications. Understanding coherence is essential for predicting fringe visibility and designing interferometric systems.