Experiment 3

Coherence Length

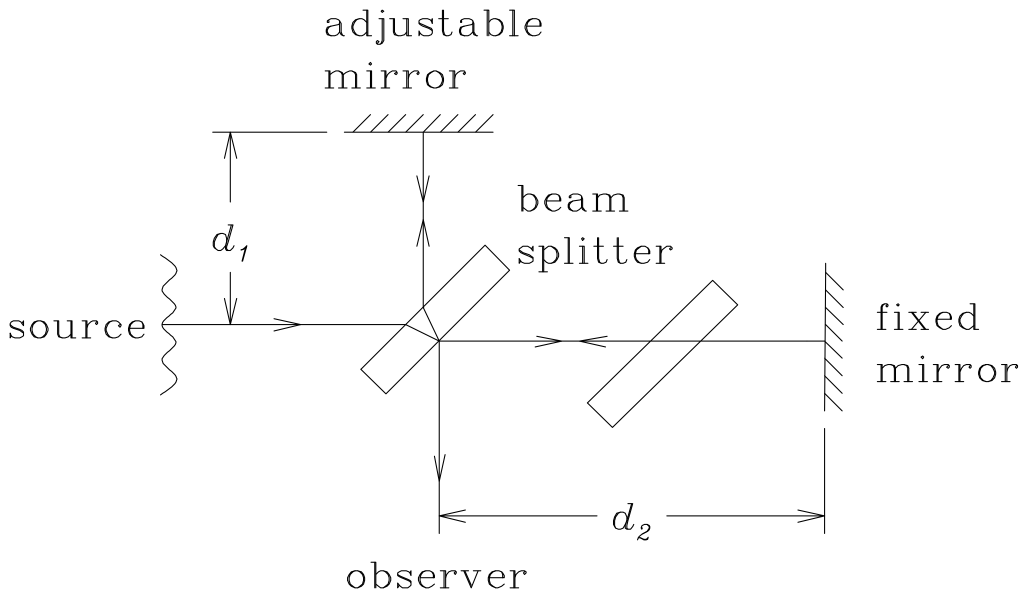
Any light source is made up of a large number of individual emitters, each of which can emit for only a brief period of time. The result is the creation of wavetrains of finite length. The average length of the wavetrains is referred to as the coherence length $\langle d \rangle$. The object of this experiment is to estimate the coherence length for several different sources using a Michelson Interferometer. In addition, the difference in wavelength between the two Na-D lines will be determined.

3.1 Outline of Theory

3.1.1 Coherence Length

A Michelson Interferometer, as previously analyzed, splits the incident beam into two beams which can travel over different distances before being reflected back to the beam splitter where the interference pattern is observed. The following fact, however, must be considered when creating interference fringes.

1. fringes are created only by the interference of two coherent sources, and
2. wavetrains from different emitters are not coherent.



This indicates that interference will only be observed if the two sections of a specific wavetrain split by the beam splitter return to the splitter at nearly the same moment to order to interfere with each other.

The coherence length can be estimated experimentally by measuring the optical path difference ($\Delta = 2(d_2 - d_1)$) at the point where the fringes become invisible. The coherence length is

$$\langle d \rangle \approx 2\Delta$$

The value obtained will depend on the sensitivity of the observer's eye, so it can only be defined as an estimate.

As part of the experiment, you will be expected to compare your results with the theoretical estimate for coherence length. As developed in lectures, the coherence length of a wavetrain emitted by a non-monochromatic source is

$$\langle d \rangle \approx \frac{\langle \lambda \rangle^2}{\Delta \lambda}$$

where $\langle \lambda \rangle$ is the average wavelength emitted by the source, and $\Delta\lambda$ is the difference in wavelengths between the shortest and longest waves emitted.

3.1.2 Na-D Doublet

A sodium (Na) lamp produces a nearly monochromatic light consisting of a doublet in the yellow region. Because these are individual sharp lines as opposed to a band of frequencies, $\langle d \rangle$ is too long to measure with the interferometer. It is, however, possible to determine the small difference in wavelength ($\Delta\lambda$) between the two lines. Shown in figure 3.1 is a graph of fringe intensity versus difference in path length (Δ). At Δ equal to zero, both of the doublet wavelengths are in phase resulting in intense fringes. As Δ is increased, the intensity drops because the fringes for the two wavelengths no longer fall at the same point. A minimum is reached when the dark fringe for one frequency falls on the bright fringe for the other. One set of returning waves is in phase while the other is out of phase. The result is a faint pattern. Increasing Δ beyond this brings the waves back into phase and increases the intensity again as shown.

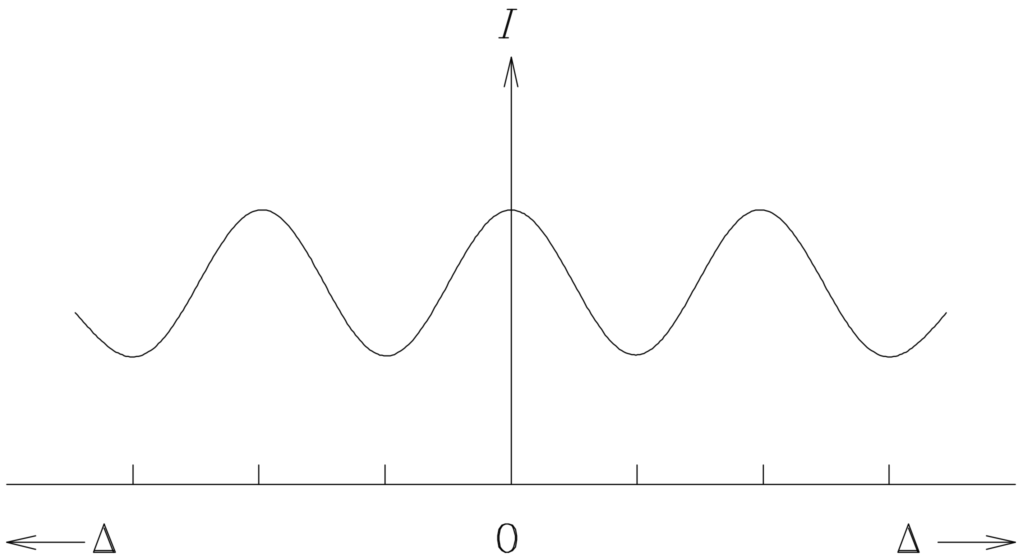


Figure 3.1: Fringe intensity versus path length

Analyzing the optical path difference at the first minimum,

$$\left(K + \frac{1}{2}\right)\lambda_1 = K(\lambda_1 + \Delta\lambda) = \Delta$$

where λ_1 and $\lambda_1 + \Delta\lambda$ are the two wavelengths and K is the number of fringes between $\Delta = 0$ and the minimum for the longer wavelength. Solving for $\Delta\lambda$ gives

$$\Delta\lambda \approx \frac{\lambda_1^2}{2\Delta} \approx \frac{\langle\lambda\rangle^2}{2\Delta}$$

The average wavelength for the doublet is 589.3 nm.

3.2 Procedure

3.2.1 Calibration

1. Calibrate the micrometer screw of the Michelson Interferometer using the green Hg-line of λ=546.1 nm. Follow the procedure presented in Experiment 2. You result should be of the form "1.00 mm on the micrometer corresponds to a change in optical path length of ... metres".

2. Find the position where the path difference between the two arms is zero.

3.2.2 Coherence Length

1. Measure the coherence length of white light using the method discussed in section 3.2.1. Compare your experimental result with the theoretical prediction for $\langle d\rangle$.

2. Repeat the coherence length measurements for

3. white light plus green filter

4. white light plus green Fabry-Perot filter

5. green light from a Hg lamp plus green filter

3.2.3 Coherence Length of a He-Ne Laser

The red light from a He-Ne laser has a very narrow band width and therefore a long coherence length. For this reason it requires the use of a much larger Michelson Interferometer. The instructor will explain the larger interferometer and assist you in measuring the coherence length.

3.2.4 Wavelength Difference of Na-D Doublet

Determine the optical path differences for the first minima on either side of the zero position. Use this information to estimate the difference in wavelength for the two D-lines and compare this with the actual value.