2. The Michelson Interferometer (Older Pasco 9255 and Ealing equipment version)

2.1. Laser Safety

This experiment makes use of diode and/or Helium-Neon lasers. Lasers can cause retinal damage if used improperly. ***In order to avoid this, never look into a laser and its output beam***. This means you must be aware of the beam's location. If the beam is being reflected, refracted or split, you must also know the path of those beams.

The lasers in this lab are Class II[1] which are not harmful normally, unless a person deliberately stares into the beam. Laser protective eye-wear is normally not necessary as the person will usually look away or close their eye. Flash blindness can occur. Any focusing or concentrating of the beam could increase the risk to one's eyes.

2.2. Purpose

In this experiment, the Michelson Interferometer is used

- to measure the wavelength of light from a helium-neon laser.
- to measure the refractive index of air.
- to measure the separation between the D lines in the emission spectrum of sodium.
- to detect white light fringes and measure the refractive index of glass.

The interferometer is fully described in most standard optics texts. The following are useful references: Jenkins & White, Fundamentals of Optics; Wood, Physical Optics; Shong, Concepts of Classical Optics.

Figure 2.1 shows the positions of the components in a Michelson Interferometer. A fringe pattern is observed on a screen placed at the bottom of the diagram where the light exits. If the light source is not overly bright, the fringe pattern is directly observed with the eye. Otherwise it is projected onto a screen.

2.3. Theory and Experiments

NOTE: The first two experiments use the Pasco interferometer. It is much more easily aligned than the Ealing interferometer. The Ealing interferometer is used for the second two experiments: the sodium D line measurement and white light fringes. Your lab demonstrator will show how the interferometer is adjusted. Please do not adjust the Ealing interferometer.

2.3.1. EXPERIMENT: Wavelength of light from a helium-neon laser.

Adjust the interferometer to produce circular fringes as discussed in the reference text. With the mirrors plane parallel circular fringes can be observed. If the two planes are not parallel, i.e. they form a wedge shaped air gap; the fringes look straight or are slightly curved. By recognizing the fringe pattern and the way it changes with fine adjustment of the mirror mounts, you will soon be able to set up the required fringe pattern. The light of a red HeNe laser has a wavelength of 632.8nm in vacuum. The micrometer screw on this Pasco interferometer moves the mirror 25 microns for each rotation.

[1] output power $\leq$ 1mW, visible wavelengths only

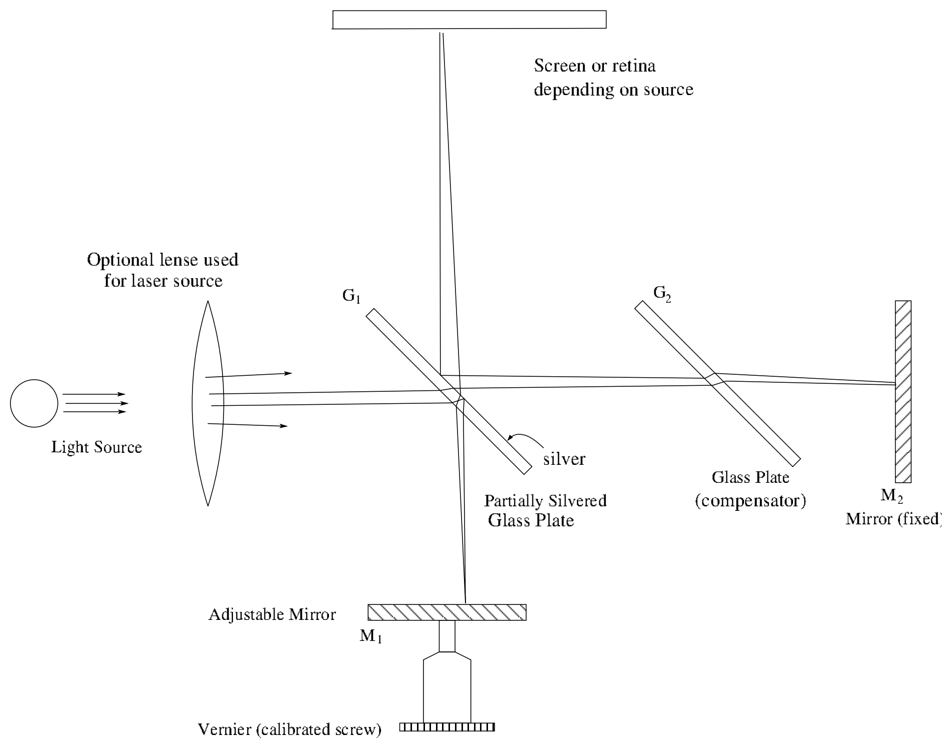

Figure 2.1.: Michelson Interferometer.

To calculate the wavelength of the source it is simply a matter of measuring the distance that one mirror moves to move the pattern one fringe, i.e. create or destroy one fringe.

For m fringes created or destroyed

$$2d = m\lambda \tag{2.1}$$

Count fringes as a function of distance moved and plot a graph m as a function of d, and hence from the slope calculate λ. Measurements of d every twenty fringes, with a total fringe count of at least two or three hundred is a reasonable basis for measurement. You will find that the data is very precise and you will probably be able to see from the graph if you miscount.

2.3.2. EXPERIMENT: Measurement of the refractive index of air.

(See Jenkins and White, 2nd ed.., p. 249; 3rd ed., p. 256)

If a thickness t of a substance having a refractive index n is introduced into one arm of the interferometer, the optical path of that arm is increased because light travels more slowly in the substance than in vacuum, and consequently the light has a shorter wavelength (the frequency does not change).

In this part of the experiment an air cell is introduced into one arm and the air is nearly exhausted. With the cell at atmospheric pressure the optical path is nt, whereas it is t with a vacuum. Thus the change in optical path is $\Delta t_{1pass} = (n-1)\,t$.

Since the light traverses the cell twice the total change in optical path is

$$\Delta t_{2pass} = 2\,(n-1)\,t$$

A change in total optical path of will cause a number of fringes m to be created or destroyed, where

$$2\,(n-1)\,t = m\lambda \tag{2.2}$$

Rather than simply measuring m for complete evacuation of the air cell, in this experiment measure the fringe shift as a function of pressure change. The relationship applicable is the above with the addition of ratios of temperature and pressure: $2\,(n-1)\,t\frac{273[K]}{T[K]}\frac{P[mmHg]}{760[mmHg]} = m\lambda$ or:

$$2\,(n-1)\,t = m\lambda\frac{T[K]}{273}\frac{760[mm\,Hg]}{P_{cell}} \tag{2.3}$$

where $P_{cell} = P_{room} - P_{gauge}$ is the initial pressure in mm Hg

P_g is the varying gauge pressure reading during the measurement phase in mm Hg

P_{room} is the room pressure in the lab

T the absolute temperature of the gas in the cell in Kelvin

m is the fringe number with 0 occurring at minimum P_{cell} for our purposes.

t is the length of the air cell $= 4.95cm \pm 0.05cm$ for the gray Ealing cell and $3.81cm \pm 0.05cm$ for the black Pasco cell, $3.00cm \pm 0.05cm$ for gray Pasco cell.

When P_{cell} is replaced by $P_{room} - P_{gauge}$, Equation 2.3 can be rearranged into the form of $y = (slope)x + b$ as shown in equation 2.4, where y is the fringe count m, and x is the variable pressure P :

$$m = -\frac{2\,(n-1)\,t}{\lambda}\frac{273[K]}{760[mmHg]T}\cdot P_{gauge} + \frac{2\,(n-1)\,t}{\lambda}\frac{273[K]P_{room}}{760[mmHg]T} \tag{2.4}$$

Miscounting of fringes which is easily done, can be seen clearly on the graph and corrections made.

1. Measure the temperature and barometric pressure of the lab. A barometer is located in the SW corner of BB2-35 and has a vernier scale allowing measurement of pressure to $\frac{1}{10}th$ of a millimeter.
2. Mount the air cell in position in the path of the beam which is traveling to the movable mirror. A small hand-pump is used to reduce the pressure in the cell. Evacuate the cell as much as the pump will allow, which gives the initial minimum pressure P_{cell} at maximum P_{gauge}.
3. Leak air slowly into the air cell and count fringes m while recording the pressure readings on the gauge P_{gauge}. Collect about eight points from the lowest pressure to room pressure.
4. Plot m as a function of P_{gauge}, which will yield a straight line graph with the slope:

$$slope = -\frac{2\,(n-1)\,t}{\lambda}\frac{273}{760T} \tag{2.5}$$

2.3.2.1. Question

1. Determine a second value for n from your graph of your data. Consult equation 2.4.

2.3.3. EXTRA EXPERIMENT: Measurement of the separation of the D lines in the spectrum of sodium.

Change to the Ealing spectrometer for the rest of the lab. The emission spectrum of sodium contains a number of lines in the visible region of the spectrum, the most intense being two closely spaced lines in the yellow-orange region.

For a single spectral line of λ_1, using the interferometer

$$2d = m_1\lambda_1$$

For a line with wavelength λ_2, a different number of fringes would pass in the same distance

$$2d = m_2\lambda_2$$