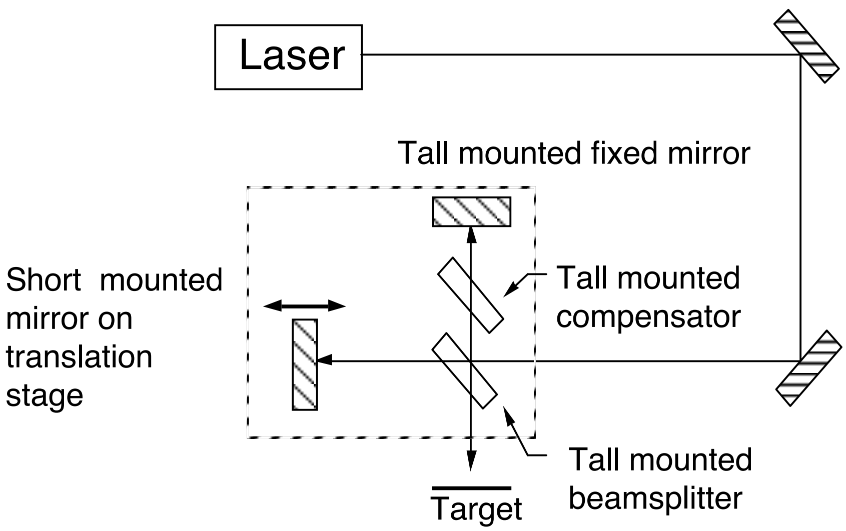
**PH 481/581** **Physical Optics** **Winter 2020**

**Laboratory #3** **Week of January 27**

Read: pp. 416-421 of "Optics" by Hecht
Do: 1. Experiment III.1: Michelson Interferometer: align and measure $\lambda$ of HeNe
2. Experiment III.2: White Light Fringes

## Experiment III.1: Michelson Interferometer: align, calibrate, and measure $\lambda$ of HeNe




The goal of this lab is to familiarize yourself with the Michelson Interferometer, to align it properly, and to measure the wavelength of the laser. The figure shows a schematic of the Michelson Interferometer you will use. Set it up so that the output of the interferometer is directed off the table towards you, place the interferometer far enough from the edge that there is room for a detector or target at the output. This configuration is not great in terms of safety for the part of the experiment involving the Helium-Neon laser, but is very useful for the rest of the experiment. Be sure to use the target when using the Helium-Neon laser. **Do not under any circumstances look into the interferometer output when using the laser** (even though you will do this when using the lamp sources).

To align the interferometer, first use the alignment procedure so the laser beam is parallel to the table top, and ensure that the beam passes through the approximate center of the beamsplitter and movable mirror. Realign your beamsplitter and fixed mirror so that the beam reflected off the beamsplitter hits the center of the fixed mirror. Make sure that your mirrors are approximately equidistant from the front side of the beamsplitter. Block the fixed mirror and send the reflection of the movable mirror back to the laser. Repeat for the fixed mirror.

There should now be two or more reflected beams on the target. Carefully adjust the movable and fixed mirrors so that the beams overlap on the target. At this point you may already notice some interference fringes. To make things more clear, convert the parallel laser input beam into a diverging beam (i.e., a point source) by inserting a diverging lens (-25 mm works well) in front of the interferometer. You should then see a set of concentric circles (a bull's eye pattern). These are the fringes formed by the interference of the two beams that have traveled through the two arms of the interferometer. Careful adjustments of the interferometer mirrors will allow you to center this pattern.

If we let $d$ be the difference in path lengths of the two arms of the interferometer, then the pattern of concentric circles is described by the equation

$$2d\cos\theta_m = m\lambda \qquad \text{Eq. 1}$$

where $m$ is an integer and $\theta_m$ is the angle of the $m$th dark ring (due to constructive interference). As you change $d$ by moving one of the mirrors, the size of the pattern will change. As $d$ approaches zero, the pattern gets large, and in principle, the dark fringe at $d = 0$ will fill the screen. In practice, you will see a hyperbola form at the center that is hard to see due to astigmatism and imperfection in the optics as well as alignment. Demonstrate this behavior.

To measure the laser wavelength, one merely has to move the mirror and count the fringes that "go by". The center of the pattern at $\theta = 0$ will act as a source or sink of fringes. If we record the appearance or disappearance of $N$ fringes during a displacement $\Delta d$ of the mirror, then Eq. 1 yields

$$\lambda = \frac{2\Delta d}{N} \qquad \text{Eq. 2}$$

which is equivalent to saying that we will see one fringe every time that $d$ changes by $\lambda/2$.

*Counting Fringes by Eye*

One mirror of the interferometer is mounted on a translation stage. You will count the $N$ fringes that you see on the target and use the translation stage controller to determine $\Delta d$, and then use Eq. 2 to find $\lambda$. Be careful of sudden movements that will disturb the interferometer and the reliability of your measurements. The reaction force acted upon the base of the translation stage due to the motor may throw off measurements. It is best to have the motor turning before beginning to count fringes if you can set it to move slowly enough. It does not matter which way the stage moves, just be careful to avoid running to the end of the travel. You can adjust the max speed, step size, and acceleration to the max speed under "settings." You should be able to use this method to get results close to the actual wavelength of the Helium-Neon laser, which is 632.8 nm. Count at least 20 fringes and the distance several times to reduce the uncertainty in your measurement of the wavelength.

*Counting Fringes with Technology*

For this part, use a photodiode to detect the fringes, rather than your eye. Place the photodiode at the center of the output of the interferometer so that the innermost circle fills the aperture. Use an iris or lens to ensure that no other fringes hit the detector. You can also use a toilet roll tube to remove room light noise from the photodiode. If you move the stage at a constant speed there will be a sine wave on the oscilloscope. The frequency of the sine wave can be related to the velocity of the translation stage using Eq. 2. Thus you can determine the wavelength by measuring the sine wave frequency and the stage velocity.

*Calibration Issues*

In both of the experiments above, you relied on the stage controller to provide one of the important pieces of data. In this case, you have no way of verifying that information. In many real world applications, the laser wavelength is already well known and the experiments above are used to calibrate the stage motion. Once you have done that, you can then reliably use the stage motion to measure another unknown wavelength.

*Polarization and Index of Refraction*

Before going to the next experiment use a polarizer in each arm of the Michelson Interferometer to verify the first Fresnel-Arago law (see p. 396-397 and p. 420 of Hecht), which says that orthogonal polarization states cannot interfere.

What happens if you stick a microscope slide into one of the arms? If you use a heat gun to carefully heat the microscope slide? Explain.

## Experiment III.2: White Light Fringes

Make sure that your interferometer is capable of moving through the point where a hyperbola appears, with the bullseye pattern on either side of that. You may need to adjust the mirror tilt to re-center the pattern as the stage moves. Now move the stage so that the hyperbola is as large as possible (this will be the “zero-point”) and then move it away a little bit (~1 mm or less) from this point. Set the stage motion so that the step size is very small, and you can see the pattern move clearly as you jog the stage. **Turn off your HeNe laser.**

You should now be able to observe interference from the fluorescent room lights. These emit a strong green line that has a small but not tiny coherence length. Place a white piece of paper at the input of the interferometer so it is well illuminated by the room lights and look with one eye into the output of the interferometer. You should be able to see faint green interference rings. Now slowly move the stage toward the “zero-point”. If your step size is small enough and you watch carefully, the green rings should develop more contrast and eventually a full spectrum of light will appear. At the point you can also use the halogen desk lamp, which has a smaller coherence length. Discuss your findings.

Equipment needed:

| Item | Qty | Source (part #) |
|---|---|---|
| Helium-Neon Laser | 1 | Melles Griot 05 LHP 121 |
| Sodium vapor lamp | 1 | |
| Base plate | 1 | Thor Labs BP2 |
| Translation stage | 1 | |
| Controller (with Power cable and USB cable) | | |
| Photodiode | 1 | Thor Labs |
| Oscilloscope | 1 | Tektronix |
| Mirror mount | 4 | Thor Labs KM1 |
| Al mirror | 4 | Newport 10D10ER.1 |
| Beam splitter | 1 | Newport 10B10BS.1 |
| Compensator | 1 | Newport 10B10 |
| -25 mm lens | 1 | Newport KPX043 |
| Iris (adjustable) | 2 | Thor Labs ID12 |
| Mounting posts | 10 | Thor Labs P3 |

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|---|---|---|
| Polarizer | 2 | Edmund A38,396 |
| Microscope slide | 1 | |
| Index note card | limitless | |
| Laser block | 1 | |
| Ruler | 1 | |