Lab 4 – The Michelson Interferometer

The Michelson interferometer is a device that produces interference between two beams of light. A diagram of the apparatus is shown in Fig. 1. Light from a light source is split into two parts. One part of the light travels a different path length than the other. After traversing these different path lengths, the two parts of the light are brought together to interfere with each other. The interference pattern can be seen on a screen.

![Fig. 1: The Michelson Interferometer](image)

Light from the source strikes the beam splitter, which allows half of the radiation to be transmitted to the movable mirror. The other half of the radiation is reflected towards the fixed mirror. The compensator plate is included in this path to insure both paths have the same optical path length when the two mirrors are equal distance from the beam splitter. After returning from the movable mirror, half the light is reflected to the light detector (screen or photodiode). Likewise, half the light from the fixed mirror is transmitted to the detector. The detector images the superposition of the two beams, which is affected by their interference.

In this experiment, we will observed the intensity pattern as a function of the position of the movable mirror. We will do this for light with a single frequency and also for light that contains two frequencies.

Remember that the intensity that results from interference is related to the difference in the path lengths of the light:
where $I_1$ is the intensity of the light source, $I_2$ is the intensity of the second, and

$$\delta = k(s_1 - s_2) \quad [2]$$

$k_1$ is the wave number of the light source, $s_1$ is the path length of the first light source and $s_2$ is the path length of the second.

For light containing two frequencies, then you get two versions of equation [1], one for each frequency.

If the ratio of the intensities of each beam is

$$r = \frac{I_2}{I_1} \quad [3]$$

and if, within a single beam, the ratio of intensities in each wavelength is

$$a = \frac{I_{\lambda_2}}{I_{\lambda_1}} \quad [4]$$

is the ratio of the intensities of the two different frequencies/wavelengths, then the total intensity at the screen, which is the sum of $I_{\lambda_1}$ and $I_{\lambda_2}$, is:

$$I = I_1(1 + r)(1 + a) + 2I_1\sqrt{r} \left(\cos \delta + \cos \delta' \right) \quad [5]$$

where $\delta$ is calculated for one frequency and $\delta'$ for the other. Using the trigonometry identity:

$$\cos \delta + \cos \delta' = 2 \cos \left( \frac{\delta + \delta'}{2} \right) \cos \left( \frac{\delta - \delta'}{2} \right) = 2 \cos \left( \frac{k_1 + k_2}{2} \Delta x \right) \cos \left( \frac{k_1 - k_2}{2} \Delta x \right) \quad [6]$$

we see the result is a fast oscillation at the mean wave number frequency and a slow envelope at the wave number difference frequency.

**Experiment**

The experiment consists of two parts: calibration of the stepper motor using the diode laser and then the measurement of the wavelength of the two sodium lines using the calibration.

**Calibration of the stepper motor**

First look at the stepper motor. Make sure you can smoothly couple and decouple its coupler to the apparatus. With the coupler uncoupled, turn on the motor and observe the direction of spin. It only spins in one direction. Now, by hand, set the position of the
movable mirror so that it will have plenty of room to move before hitting the end of its carriage.

First we need to align the apparatus. Aim the beam into the apparatus. Make sure the beam is properly retro-reflected. You should see two bright spots on the observation screen. Adjust the angle of the fixed mirror until these two spots overlap. The more carefully you do this, the better the resulting interference pattern will be.

Now, take a 15 (or 25.4) mm converging lens and put it between the laser and the apparatus, close to the apparatus. Use the plano-convex lens so you can align it using retro-reflection. If you have properly aligned the device, you should see a pattern like the one in Fig. 2. (Actually, you will see two things like this: one is the normal interference pattern of our diode laser and the other is these new fringes. Often the new ones first appear as very fine nearly horizontal or vertical lines. By carefully adjusting the fixed mirror, those lines can be thickened and centered. You can tell the difference between the two sources of bullseye because one moves when the mirrors move and the other does not.)

Fig. 2: Typical interference pattern from the Michaelson Interferometer.

If you do not see this, adjust the alignment until it will good enough. Try slowly and carefully adjusting the fixed mirror to first make the fringes as broad and possible and then to center the bulls eye.

We will use the photodiode to measure the brightness of the center dot in this pattern as a function of the position of the movable mirror (it is fine if the iris is a bit wider and takes in a fringe or two). Since the image is very dim, use the highest gain setting on the photodiode. Also, note that there is a new amplifier on the table. The output of the photodiode should go into this amplifier, and the output of the amplifier should go into the old device.

Now make sure the stepping motor is coupled to the movable mirror and turn it on. You should now see the fringes appearing and disappearing as the path-length difference between the two mirrors changes. In this lab, unlike previous labs, you will be measuring intensity versus time instead of versus step number or the value of the loop counter in your code. When you are in a loop, though, the time to execute it is not fixed because of random computer services. So, you the “tic” and “toc” functions of matlab to initialize and retrieve the time (use the help function of matlab to get more documentation). Don’t put anything inside the loop except taking the data and retrieving the time.
The interferometer level arm reduction factor is 5X (the movable mirror moves 1/5 the distance of the micrometer), so that the wavelength of the light can be found using:

$$\lambda = \frac{1}{5} \left( \frac{2d}{m} \right) \quad [7]$$

where \(d\) is the distance the micrometer moves and \(m\) is the number of rings that disappeared (or appeared) during the movement. Note that for a given \(D\), the moving mirror moves by \(d/5\). (Ask yourself: Why do we need the factor of 2?) Use the synchronous motor to facilitate the turning of the micrometer. As the micrometer is turning, record the interference data with the photodiode. The motor runs at approximately 0.5 rpm and the micrometer moves at approximately \(5 \times 10^{-4} \text{ m/rev}\). Use this to check that your result is reasonable, and then exact more precise values for these numbers from your data.

**The Sodium Lamp**

Remove the converging lens and place the sodium lamp as close to your apparatus as possible. Ask your instructor to make the lights as low as possible, as the resulting image will be very low intensity. If you do not see a good bulls eye, put the laser back in and realign using it and then try again. If, after making the most perfect bulls eye you can with the laser you still cannot see any sodium fringes, you may need to dim the sodium lamp using the large iris on the table. Also try setting the micrometer between 3 and 5 mm. You will need to take very long runs (30 minutes) to get good data, so make sure the movable mirror is set so it can do this. Your goal is to measure the two wavelengths of the sodium doublet.

Note that each of the double lines are not monochromatic due to broadening from pressure effects and the motion of the atoms in the lamp (Doppler effect). This means the coherence length is not that large. If the path length difference is too large, you will not see any fringes.