Michelson Interferometry
PHYS 310 – Spring 2018

Overview

The Michelson interference experiment is one of the great "classics" of physics. Like Beethoven's 9^{th} Symphony or the Beatles' Abbey Road, it has been around for a long time and yet it remains as current as always. This experiment is tremendously important for several reasons:

- It illustrates the most basic principles of constructive and destructive interference. This is relevant not only to a study of optics, but also to quantum mechanics as well. In fact, there have been some very recent experiments (and many on-going ones as well) that apply the principle of Michelson interferometry to beams of atoms and molecules.

- The Michelson Interferometer plays a significant role in the history of physics. Probably the most famous use of this device is from the 1887 Michelson-Morley experiment that played a major role in discounting the idea of an "aether" through which light propagates in space. This was one of the main experimental underpinnings for Einstein's theory of relativity. Michelson interferometry is also the technique that is used in current experiments to detect gravitational waves. And, of course, evidence was **found** just in the past few years (late 2015) of gravitational waves from two colliding black holes (this experiment won the 2017 Nobel Prize), and that detection was made possible by Michelson interferometry.

- It remains one of the most sensitive devices for measuring wavelengths, distances and index of refraction variations. In this experiment, you'll be able to measure wavelengths down to a precision of a nm, and variations in wavelength to a precision of 10^{-12} m (i.e., a pm). To this day, the Michelson technique is used for some of the most sensitive measurements, and there are automated devices that are based on the Michelson device.

It is also a remarkably simple apparatus – part of the awe of this experiment is the ability to get such precise results from such a simple system.

The goals of this experiment are (a) to expose you to principles of interference and how they can be used to make extremely precise measurements; (b) to give you some experience in experimental design; specifically, determining the best experimental protocol to obtain good results with small uncertainties that aren't tainted by systematic errors; (c) to give you a taste of some of the kinds of very sensitive measurements and techniques that can be made/done based on the principles of the Michelson interferometer.

Tasks

We are not going to give you a step-by-step manual for this experiment. Rather, we present you with a series of tasks, and leave it to you to (a) figure out how to complete the tasks; (b) look up information needed to help you figure this out; or (c) ask me for help (we're not going to leave y'all *completely* in the dark here).

Throughout this experiment (***and throughout the semester!!***) document everything that you do in your lab notebook, including diagrams of the apparatus and any data analysis and graphs. You can also take some cell phone pictures and tape them into your book.

1. To start, read Chapter 13 of *Fundamentals of Optics* by Jenkins and White. The first few pages should be a review, but the sections on the various interferometers and the phenomena seen through them will be new. Don't spend a lot of time on sections 13.5-13.7, but try to understand how the devices described therein work. Study sections 13.8-13.10 on the Michelson interferometer. The remainder of the chapter is interesting, but of less direct importance for this lab.

   Homework: determine a relation for the intensity of the light viewed at the center of the pattern ($\theta = 0$) as a function of Δx (the difference in the distance between the beam splitter and the two mirrors). Also, be prepared to explain why a circular pattern of fringes is visible if the mirrors are aligned to be perpendicular to each other. Also, be able to explain why the spacing between the fringes gets larger and larger the closer d gets to zero.

2. Now familiarize yourself with the apparatus. Play around with the apparatus until you are confident that you can obtain circular fringes. This is not a trivial matter. You should start by adjusting the coarse settings on the carriage until the distances between the reflective side of the beam splitter and the two mirrors are roughly equal. (Use a caliper or ruler to check.) Then adjust the angle of the mirror until almost perfectly aligned. **NOTE: adjusting the mirror requires a LOT of patience, and it is very easy to completely mess everything up if the mirror becomes badly aligned.** And if you can see fringes already without adjusting the mirror, you are already close.

   If you need to adjust the mirror from scratch (i.e., no fringes are visible at all), do this in two steps: (a) watch the image of a sharp object (e.g., a pointy piece of tape) on the frosted screen. There should be two images, one from each mirror. Adjust until they are as well lined-up as is possible. Then (b) make very small adjustments in the mirror until you can see some fringes. They will probably be ***very*** close together the first time you see them. Once you find some fringes, then make a successive series of adjustments to the mirrors to get the fringes as centered as possible. The approach: turn one of the knobs (*very* slightly – even the most insignificant turn can make a big difference) and let go. If the fringes get farther apart, do it again in the same direction. If the fringes get closer, adjust the knob in the opposite direction. Then when things are the best with that screw, do the same with another screw. Etc. Then (c) move the carriage and see if the fringes get closer or farther. If closer, then move the carriage the other way. If farther, then keep going. You might go back to step (b) periodically to tune things.

   Note: the screws used to adjust the mirror are awful. You have to really tease them and do very small movements to have any success here.

3. Measure the wavelength of the green emission line from mercury (Hg). There are good ways of making this measurement, and there are lousy ways of making this measurement. Warning: the vast majority of web sites that talk about the Michelson experiment – and the various manuals that we have for the apparatus – specify a technique that will frequently give bad results, for reasons that we'd like y'all to try to figure out.

   A little hint here: the interferometers that we have are really good devices capable of incredible precision. But there are some idiosyncrasies associated with these devices as well, one of which you will likely discover almost immediately, and others which are more subtle. Good experimental technique will enable you to figure out what these idiosyncrasies are and help you figure out how to get results that will not be damaged at all by them.

Comments: use the spectrometer or a pair of diffraction grating glasses to look at the spectrum of the mercury lamp before doing the experiment. Note also that we have some filters that can be used to make the source more monochromatic. And put a green interference filter in front of the mercury lamp when doing the measurements.

4. Measure the average wavelength for the yellow lines in the sodium spectrum. Once you have this, determine the *difference* in wavelength $\Delta\lambda$ between the two yellow emission lines. (These two yellow emission lines are referred to as the "sodium doublet," and the Michelson experiment can determine $\Delta\lambda$ to very high precision.)

   The "M4 Interferometer" manual (NOTE: this isn't the actual interferometer that we are using) has some information on how to make these measurements, and I'll help you as well with the basic approach to determine $\Delta\lambda$. You will have to derive a relationship that can be used to determine $\Delta\lambda$ from this approach. (Again, I'll help y'all out if you get stuck.)

   Warning: the sodium source is very bright → don't look directly at the source when it is on. Also, the source needs about 10 minutes to warm up – you'll notice that it doesn't look yellow when you first start it.

5. Set up the apparatus to view "white light fringes" using a basic incandescent light bulb. Again, there are some techniques in the manual in Olin 177 – the "split-screen" approach worked really well for me, and the effect is quite dramatic once you have succeeded.

6. Enhancements: once you have completed the previous tasks, there are some other tasks that we can talk about, including using the interferometer to visualize the movement of air, measuring the index of refraction of a piece of material, … Feel free at this point also to experiment with anything that you think this interferometer will be useful for.

   What variations in air temperature can be measured with this technique? Dependence of fringing behavior on index of refraction and look up variation of index of refraction of air with temperature – can determine a temperature field.

7. Depending on the timing and on which unit it is, I might also ask y'all to report on current research projects based on the Michelson approach, including the search for gravitational waves or various experiments of quantum weirdness.