O-2

From Physics 6510/4410 Wiki

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O-2 : Michelson Interferometer [1.5 S]

Introduction

This is a straightforward experiment where you will use the Michelson interferometer to investigate interference phenomena. The Michelson setup is historically one of the most popular tools for optical interferometry, and has been used in a variety of applications. It is a very accurate length-measuring device and has been used extensively in the systematic study of the fine structure of spectral lines. Perhaps most famously, Michelson and Edward Morley once used it to help disprove the existence of the "luminiferous aether."

Description and Overview

In a nutshell, light emitted from a source is split into two beams. The Michelson setup allows a path difference to be introduced, which yields interference fringes. A schematic diagram of the Michelson interferometer is shown below.

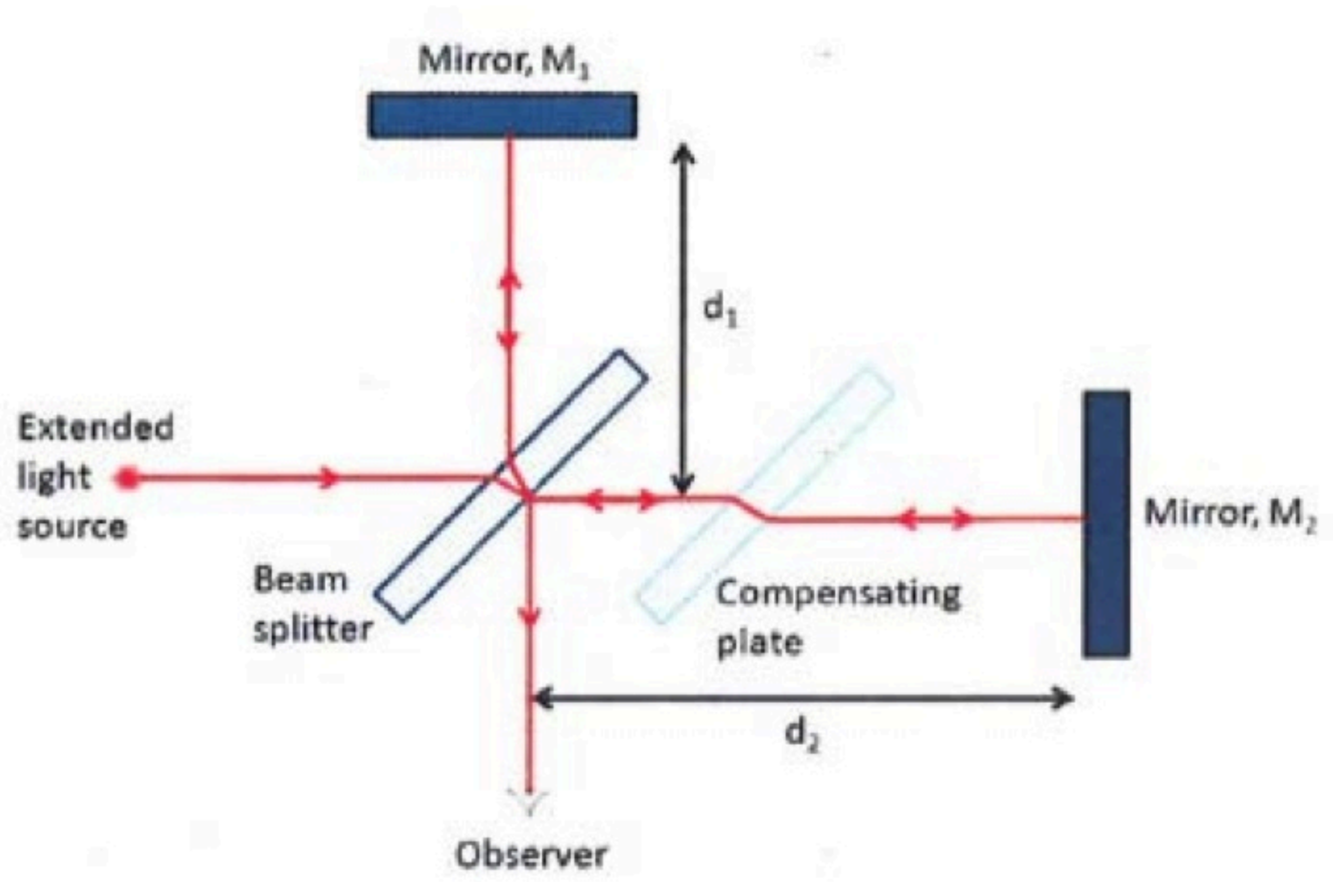

Figure 1: The Michelson Interferometer

A monochromatic extended light source of wavelength λ passes through a beam splitter at 45o and is split into two paths. The rear surface of the beam splitter is coated to reflect approximately one-half of the incident light. Along path 1 light is reflected once from the rear surface of the beam splitter; transmitted light follows path 2. Mirrors M1 and M2 reflect light back to the beam splitter where the first and second beams recombine to be viewed by the observer. A compensating plate, made of the same material (glass) and of the same thickness as the beam splitter, is placed along the path on the right, parallel to the beam splitter, to equalize the distances each beam travels through glass.

We denote the distances of the two mirrors from the beam splitter by d1 and d2, respectively, and let d = ｜d1 – d2 ｜. Because the light beams 1 and 2 travel the respective lengths d1 and d2 twice, the two beams have a path difference of 2d when recombined at the rear surface of the beam splitter. Therefore, when we change d by and integral multiple of λ/2, the fringe pattern shifts from one minimum (or maximum) to the next minimum (or maximum).

Apparatus

A photo of the apparatus used in the lab is shown below :

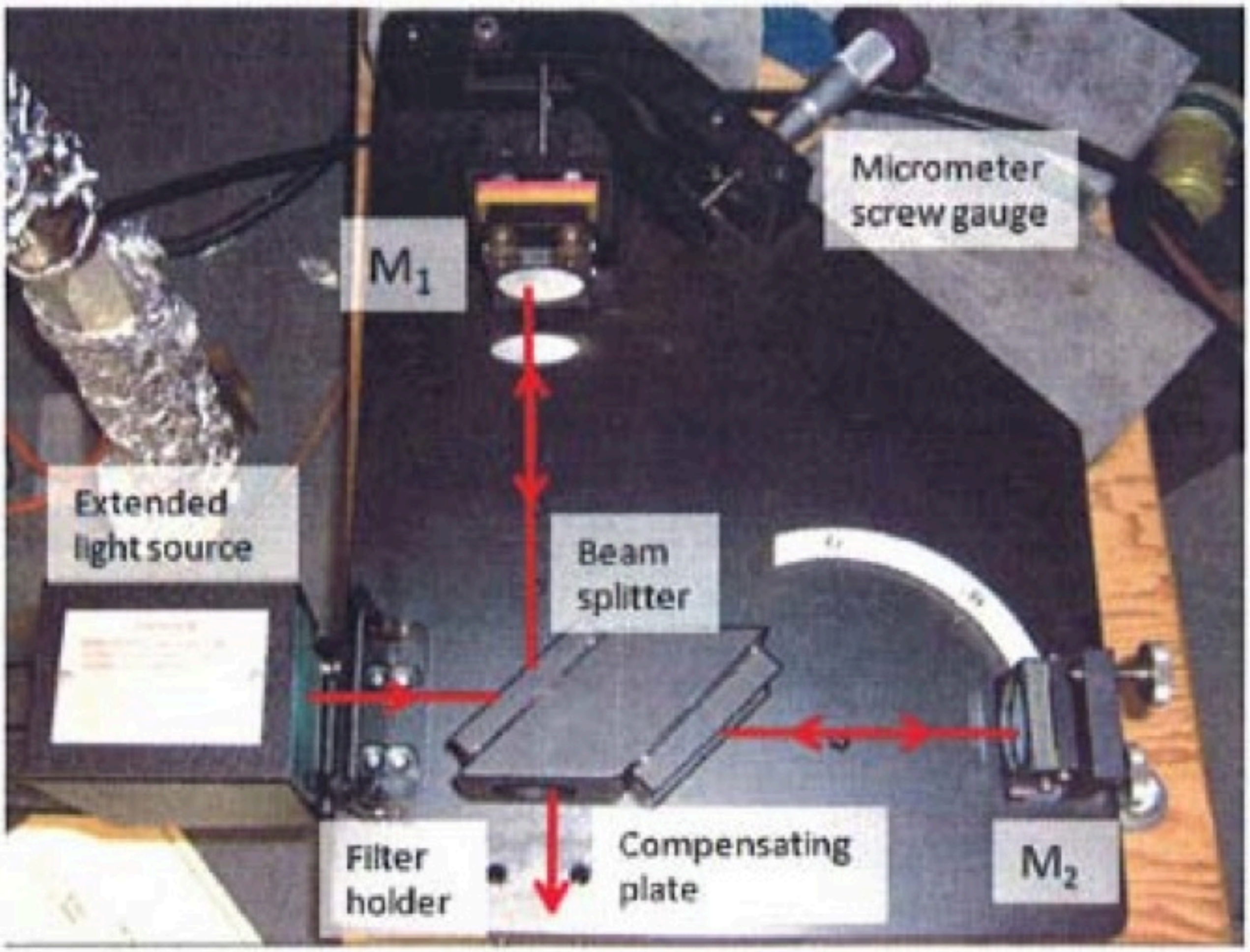

Figure 2: Photo of the Michelson Interferometer

The Michelson interferometer consists of :

- Two sources: Hg, and white light
- One half-silvered mirror
- Two mirrors: one moveable, one not
- One compensating plate
- A micrometer screw gauge, which moves the moveable mirror via a lever arm

For this setup, mirror M1 is mounted with a micrometer screw gauge which varies the distance d1. The mirror M2 is fixed, but has two knobs used to vary the angle of M2 with respect to the vertical plane. We use a twin lamp light source that can provide both mercury light and white light. Filters inserted in front of the light source are used to allow passage of light of selected wavelengths (mercury green, and mercury yellow doublet).

Look through the references to figure out the purpose of each of these!

Objectives

1. Using the (known) wavelength of the mercury green line, determine the mechanical advantage of the lever arm -- for some displacement of the screw gauge, how much does the mirror move? Next, investigate the error in use of the screw gauge. To do this, measure the number of fringes that pass in about 1 full turn of the lead screw (several thousand). If you record the setting for say, every 100 successive fringes, this will give you data to investigate the screw error.
2. To measure the wavelength separation of the mercury yellow lines, given their average wavelength, 578.0 nm.
3. To reproduce and observe the white light fringes directly, through a glass filter and through a glass filter in conjunction with an interference filter.

Additional Notes

- For calibrating the micrometer screw, because the accuracy required for d1 is on the order of the wavelength (~ 500 nm) of the light, it is necessary to accurately relate the change in the micrometer reading to the corresponding change in d1. That is, the calibration constant α defined by the relationship $\Delta d = \alpha\ \Delta x$, where Δd is the change in d1 produced by a change in micrometer value Δx. Use the mercury green line and the known value of its wavelength to perform the calibration by measuring the change in screw value for the passage of ca. 100 fringes for micrometer screw values ranging from about 0.000 mm to 2.000 mm.

- When measuring the mercury yellow doublet, consider a superposition of two closely spaced spectral lines of wavelengths $\lambda 1$ and $\lambda 2$. Show that the superposition yields an envelope with beats separated by $\lambda 1 \lambda 2 / | \lambda 1 - \lambda 2 |$. Use this to measure the wavelength separation $| \lambda 1 - \lambda 2 |$ of the mercury yellow doublet.

- When measuring the white light fringes, remember that white light is made up of a wide range of wavelengths. Each of its components produces fringes with maxima given by different values of d. The positions of these maxima coincide only at zero path difference when d=0. For sufficiently large values of d, these fringes superimpose on one another at different phases, hence recombining to produce white light. The separation of white light into the fringes of its components is visible only at small path differences. Figure 6 shows white light fringes at zero path difference. See if you can observe white light fringes at zero path difference and at slightly non-zero path differences. Notice that at zero path difference the waves from the two paths interfere destructively, producing a black fringe. Why does this occur?

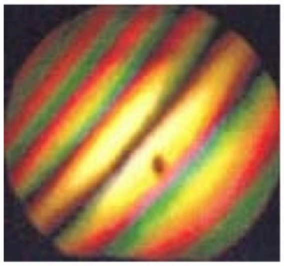

Figure 6: Photograph of White Light Fringes at Zero Path Difference

- When the two mirrors are not exactly perpendicular to each other, the path distance would also be dependent on the azimuthal angle. For the part of M2 which is tilted towards M1, a smaller θ is needed to produce the same path difference. As a result, when M2 is significantly tilted we only observe vertical or horizontal fringes, depending on the axis along which M2 is tilted. The figure below displays vertical fringes observed with the mercury green line.

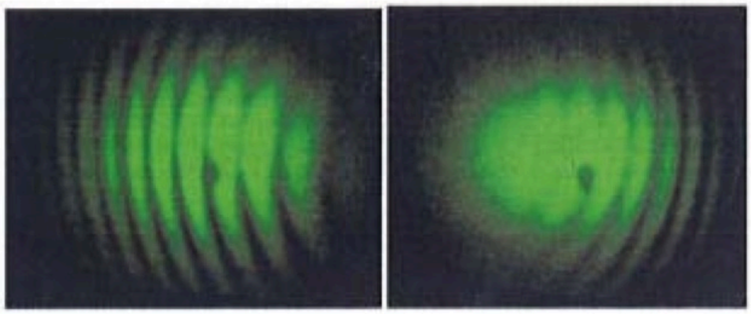

Figure 5: Photographs of Mercury Green Line Vertical Fringes Obtained by Tilting M_2 in two opposite directions.

- The figure below shows an equivalent diagram of the Michelson interferometer with the light source and M2 replaced by their respective images formed by the beam splitter.

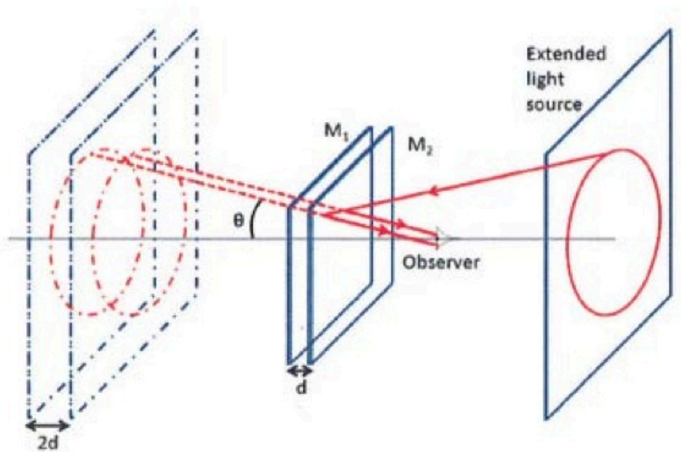

Figure 3: A simplified diagram of the Michelson interferometer, with the light source and M_2 replaced by their respective images formed by the beam splitter.

Notice that in the diagram, the light source, the two mirrors and the observer lie on a straight line. From the diagram, we see that for the light rays reaching the observer at an angle of θ, the path difference is given by 2d cosθ and, as before, we get successive maxima (or minima) corresponding to path differences mλ and (m±1)λ for some integer m. Because the path difference is independent of the azimuthal angle, we get circular fringes such that a smaller θ corresponds to a larger value of m. Notice that when d decreases, a smaller θ is needed to maintain the same multiple of λ, so we observe the circular fringes shrinking towards the center. In addition, when d=0, every θ produces the zeroth order, so the zeroth order occupies the entire view. The figure below displays circular fringes observed with the mercury green line.

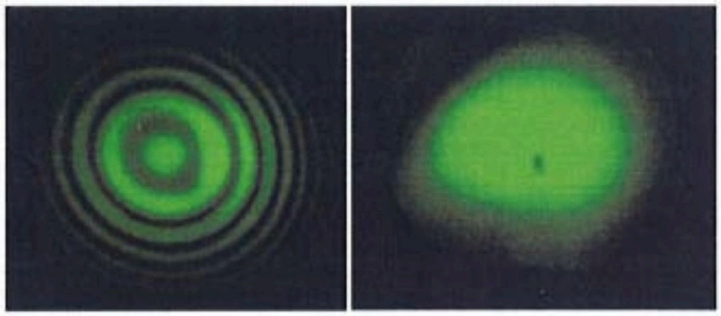

Figure 4: Photographs of circular fringes for the mercury green line (left) and the zeroth order circular fringe (right).

Safety Precautions

- The mercury lamp emits fairly intense UV radiation - make sure the glass filter is always in place before turning it on.

Experimental Tips

- Turning the lights off will make the interference patterns much easier to see!
- The white fringes can be difficult to find. Check out the first reference (Bell and Tubbs) for an interesting method.
- When viewing the fringes, you'll see a dark spot in the image. This spot doesn't move -- this makes for a good reference point when counting fringes.
- Depending on which setup you use, there may be a variety of filters lying around. For viewing the white fringes, first use the green interference filter you used in part 1, in combination with the glass filter (which should always be in!). Next try to find them with only the glass filter. Why is one easier than the other?

References

- "Use of Grating to Find Interferometer White Light Fringes", G.D. Bell and E.F. Tubbs, American Journal of Physics 37, 273 (1969) (http://ajp.aapt.org/resource/1/ajpias/v37/i3/p273_s1)
- Jenkins and White, "Fundamentals of Optics", Ch. 13 (or "Fundamentals of Physical Optics", Ch. 3)
- Wood, "Physical Optics", pp 292-305 (3rd ed.)
- Michelson, "Studies in Optics", Ch. 3, 4, 5.