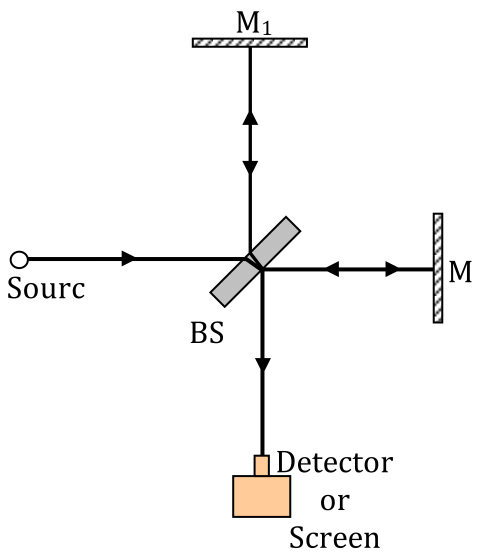
Photonics Laboratory
Physics 472
Spring 2024

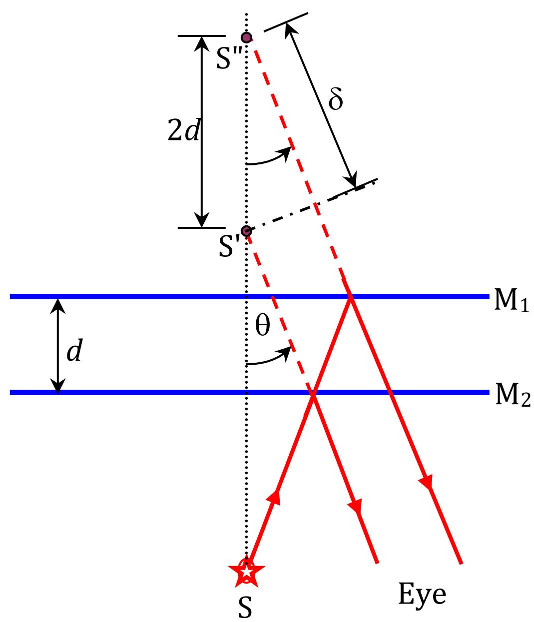
Experiment#4 Michelson Interferometer

BACKGROUND

Interference is due to the superposition of two waves or more somewhere in space at some time. It results in a change or modulation of the intensity of light. The interfering waves must physically overlap in the region where the interference pattern is detected. Keep in mind that we are talking about waves that have the same wavelength λ. If the Optical path difference, OPD, between the paths traveled by the two waves is an integral number of λ then we obtain constructive interference. However, if OPD is half-integer λ the interference is destructive. The OPD is the product of the physical distance traveled by the light beam and the index of refraction along the path of the light beam.

Michelson interferometer consists of two mirrors, a beam splitter, and a light source as shown below. To analyze Michelson interferometer, we need to simplify the problem to two beam interference. When you look into the system at the location of the eye or detector you see the mirror M_1 and a virtual image M_2'. M_2' is the image of M_2 formed by M_1. M_2' could be in front of or behind M_1. This depends on the actual distance between M_1 and the BS and that of M_2 and the BS. Further simplification will be achieved if we consider the image of the sours formed by M_1 and M_2'. The diagram below shows the transformation I just discussed.



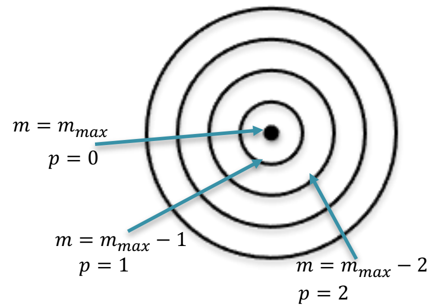


The OPD, δ, is equal to $2d\cos(\theta)$. Remember for constructive interference $\delta = m\lambda$. m is an integer that represent the fringe order. Therefore, $2d\cos(\theta) = m\lambda$.

However, there is a 180° phase shift due to reflection at the beam splitter, so this is a condition for destructive interference.

Let us find the maximum number of fringes for a given mirror separation and a given wavelength. From the interference condition equation we see that $m_{\max}$ occurs when $\cos(\theta)$ is maximum, $\theta=0$.

$$m_{max} = \frac{2d}{\lambda}$$

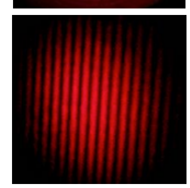


This means that the central dark fringe has order number equal to $m_{\max}$. We can rewrite the interference condition by introducing an integer p that will make the central dark fringe associate with $p = 0$

$$p = m_{max} - m = \frac{2d}{\lambda} - m$$

Rearrange we obtain, $2d[1 - \cos(\theta)] = p\lambda$

If the mirrors are parallel and $d \neq 0$ then we obtain *fringes of equal inclination*, the fringes are concentric circles. If the mirrors are tilted slightly relative to each other the fringes are straight and parallel to the line of intersection of the mirror planes and are called *fringes of equal thickness*. This situation is like a thin wedge film since the mirrors are slightly tilted relative to each other. Best starlight fringes are observed when d is very close to zero. As d gets larger the fringe thickness gets smaller and more fringes appear. If we use parallel (collimated) light, fringes of equal thickness are always obtained independent of d.



Michelson interferometer can be used to determine the wavelength of light, thickness, and index of refraction of materials. The thickness and index of refraction affect the OPD. Suppose that by changing the OPD from d_1 to d_2 the number of fringes passed by were Δm. From Michelson interferometer equation we find that $2\Delta d \cos(\theta) = \Delta m\lambda$. Then for $\theta=0$ (since we are looking at the central fringe) we obtain

$$2\Delta d = \Delta m\lambda$$

EXPERMENTS

Task#1: Calibration of the micrometer and the mirror (M1) movement

Use a short focal length lens to focus a HeNe laser operating at 632.8 nm. This makes the alignment and the calibration of the micrometer movement easier. When the interferometer is well aligned you get the concentric fringes if $d \neq 0$. Move the movable mirror, M_1, by moving the micrometer and *note the fringe movement*.

(a) Now you need to move the micrometer and at the same time count the fringes. You need to move the micrometer very slowly. *Be sure to move the micrometer in one direction to avoid any* ***backlash*****.** You need to count at least <u>100 fringes</u> as you move the micrometer from the starting point to some other distance. Repeat this 5 times. Record your data and find the average and the uncertainty in the distance measured by the micrometer.

(b) Knowing the distance that the micromere moved, the wavelength of the laser, and the number of fringes counted you should be able, with the help of the last equation above, to determine the conversion factor that relates the micrometer distance and the actual distance M_1 moved.

Task#2: Determine the wavelength of a laser

Use the same procedure of task#1 to determine the wavelength of the diode lasers provided at your station.

(a) Repeat the experiment 5 times for each of the lasers and use the average value of the micrometer readings to find the wavelengths of the lasers.

(b) Determine the uncertainty in the laser wavelength for each case.

(c) Compare your results to the accepted values for these lasers. Find the %error for each case. Does you results agree within the experimental error.

Task#3: Determine the index of refraction of a glass sample

Use the same laser and configuration in task#1 to determine the index of refraction for the glass sample at your station. In this case you need to mount the sample on a rotating stage and place it in the path of the beam in one of Michelson interferometer arms. To find the index of refraction you need to measure the OPD and the corresponding number of fringes that passes by during the rotation process.

After rotation by an angle θ from normal incidence, the beam travels larger distance than that traveled when the beam was perpendicular to the surface of the sample. Knowing the number of fringes ($N \equiv \Delta m$), the angle (θ), and the thickness of the sample (t) you should be able to find the index of refraction using the following result.

$$n = \frac{(2t - N\lambda)[1 - \cos(\theta)]}{2t[1 - \cos(\theta)] - N\lambda}$$

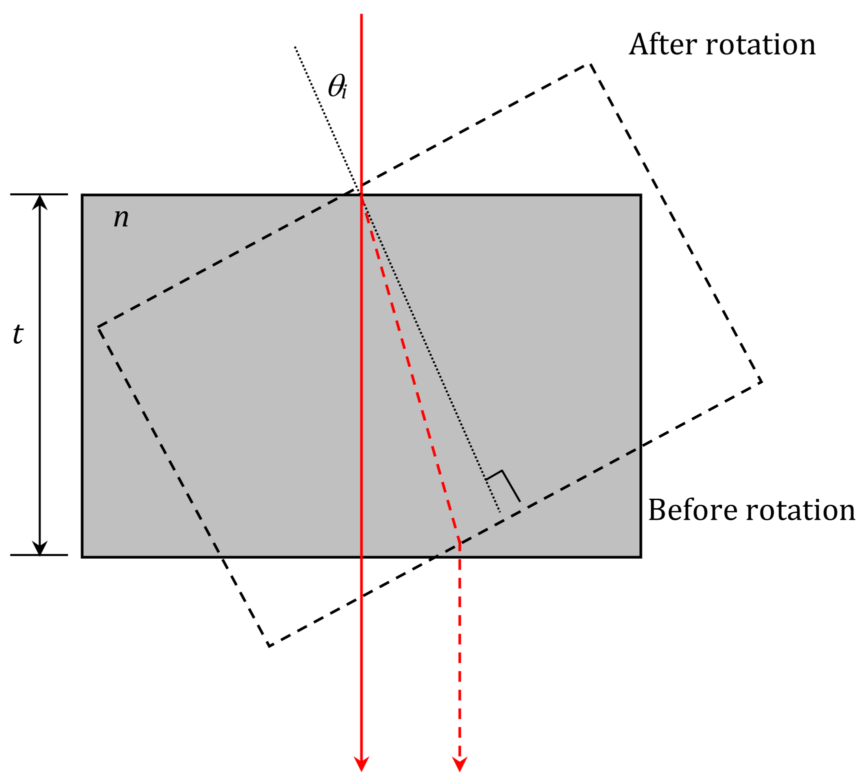
(a) Make sure that the sample is perpendicular to the laser beam, normal incidence, how?

(b) rotate the sample slowly and count 300 fringes. Record the rotation angle. Repeat this procedure starting from normal incidence 5 times. Record your data.

(c) Find the average rotation angle and its uncertainty.

(d) determine the index of refraction and its uncertainty.

(b) **Derive the above expression using the equation $2\Delta d = \Delta m\lambda$ and the diagram shown below.** ***Note, deriving this expression is not trivial.***



Task#4: Twyman-Green interferometer

What do you expect the interference to be if a collimated laser beam is used instead of a diverging one? Use the Astronomical Telescope configuration to produce a collimated enlarged laser beam. In this case the Michelson Interferometer is known as Twyman-Green interferometer.

(a) Use a microscope objective for the short focal length lens (40x or 60x). Is the interference pattern consistent with what you expected? Describe the interference pattern for parallel and tilted mirrors.

(b) Now insert a microscope slide in the path of the beam in the side of the moving mirror. Describe the resultant fringe pattern (Draw it). Explain the changes in the interference pattern if any.

(c) Insert a convex lens in the path of the beam in the side of the moving mirror. Describe the resultant fringe pattern (Draw it).

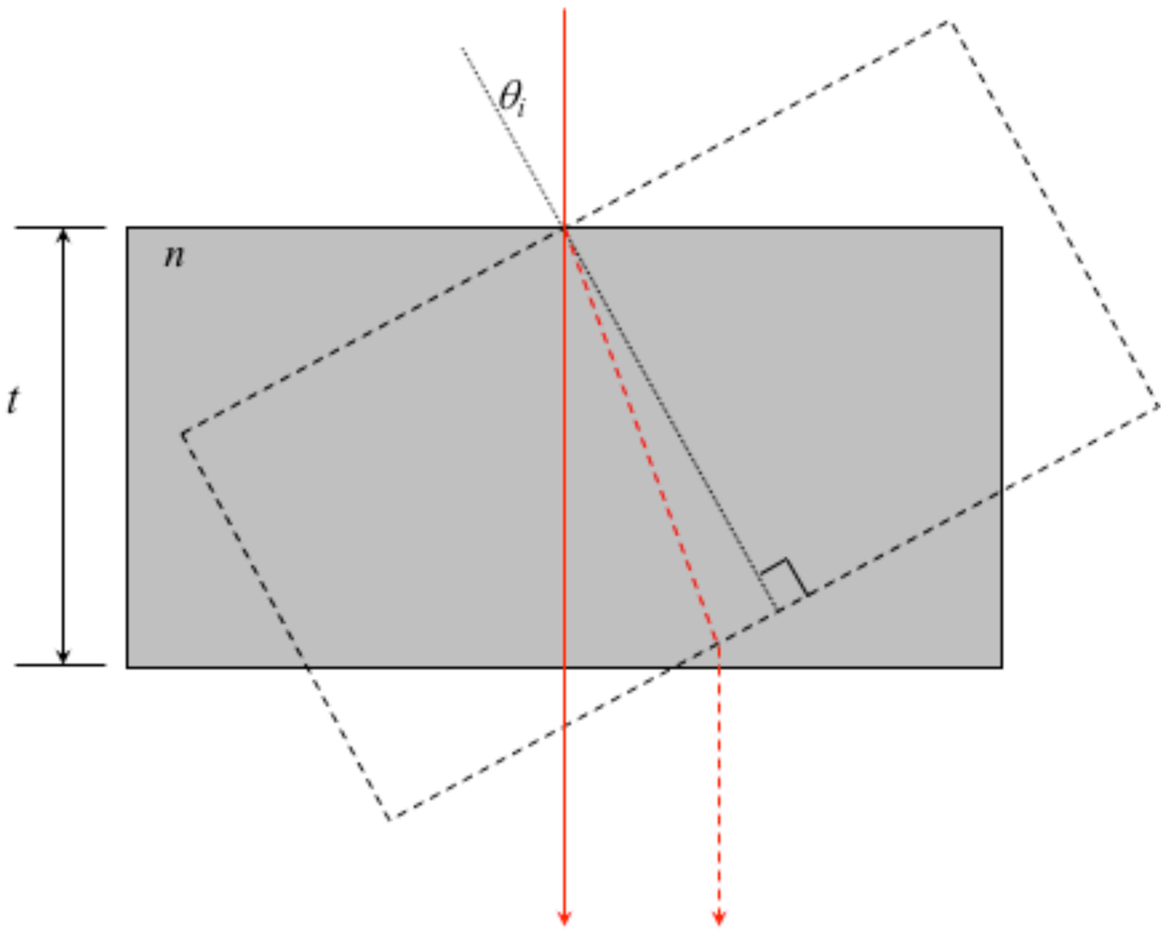
Task#5: Determine the difference between the wavelengths of the sodium light doublet

Use the sodium light source to observe fringes on the screen. Since the yellow doublet of sodium has wavelengths very close to each other, 588.995nm and 589.592nm, you should see two sets of fringes. As you move the mirror you will notice that the visibility of the fringes changes. At certain mirror separation you should see sharp or fuzzy fringes. The sharp fringes occur when the bright fringes from each wavelength coincide, and the fuzzy fringes occur when the bright fringes from one wavelength coincide with dark fringes of the other wavelength.

(a) Use the micrometer to move the mirror and find the distance moved to go from fuzzy fringes to the next set of fuzzy fringes or from sharp bright fringes to the next set of sharp bright fringes. Repeat this procedure 5 times and record your data. find the average distance and its uncertainty.

(b) Show that the relationship that relates the distance, the average wavelength, and the wavelength difference is given by $\Delta\lambda = \lambda^2/2\text{d}$.

(c) From your data find the wavelength difference between the yellow doublet of sodium. Find the uncertainty in the wavelength difference. Compare your experimental result to the known value of the wavelength difference. Find the %error in the wavelength difference and explain.



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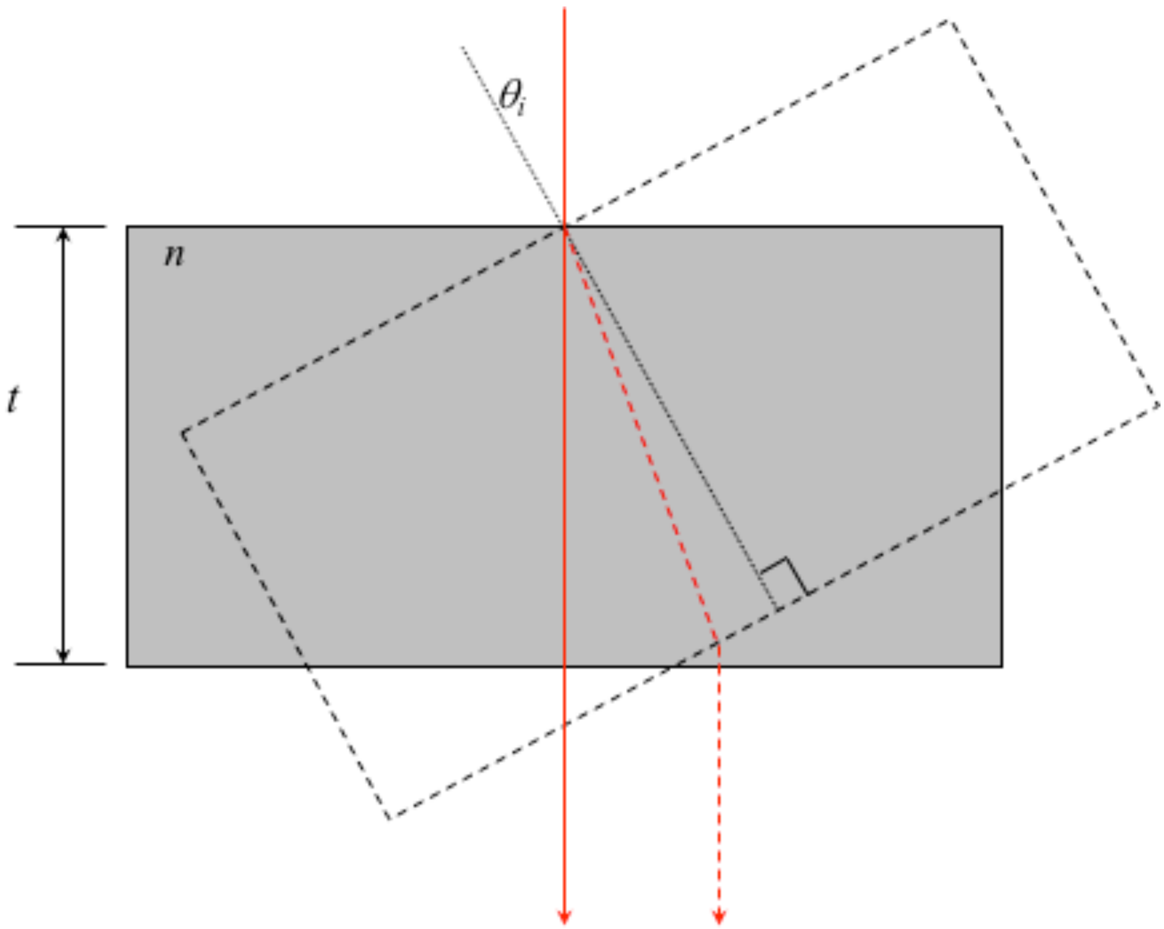

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