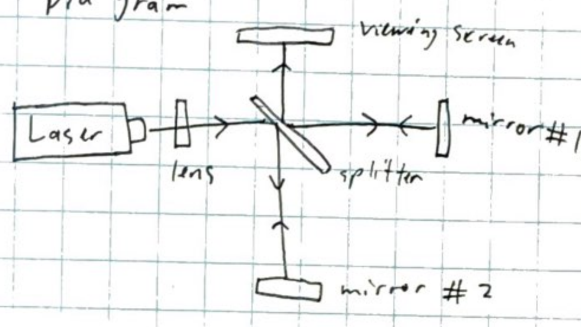
This lab measures interference patterns from ~~[illegible]~~ a laser

Laser: JDSU He-Ne Gas Laser model: 1508-1
$\lambda = 632.8$

Michelson Interferometer

Diagram



Laser shines through beam splitter that reflects 50% and transmits 50% of light.

Because beams are from same source their phases are highly coordinated.
The lens causes light to spread out making interference pattern visible on viewing screen.

Interference pattern is caused by light waves of different phases being in a super-position ~~where~~ so that minimums & maximums are created

At first beams are in phase, but if they travel different distances then they will become out of phase. Moving mirror #1 varies the path length of one of ~~the~~ the beams, changing its phase.
Beam travels path from mirror #1 to splitter twice so changing distance of mirror #1 changes the distance travelled by x2

move Mirror #1 $\frac{\lambda}{4}$ closer $\longrightarrow$ path length $\frac{\lambda}{2}$ shorter

radii of maxima

Moving mirror a distance d_m and counting ~~the~~ the number of times the fringe pattern is restored to its original state, m. can calculate the wavelength λ with: $$\lambda = \frac{2 d_m}{m}$$

Set up

Laser Alignment

1.) Set base on table w/ micrometer facing you. Put laser on bench to left perpendicular to base.
2.) Secure mirror #1 into base
3.) Turn laser on. Make sure beam is $\parallel$ to base and strikes center of mirror #1
4.) Adjust X-Y position of laser until beam is reflected back into aperture.

Michelson mode Setup

1.) Align laser

2.) Place adjustable mirrors on base and viewing screen

3.) Position beam splitter at 45° angle to beam adjust so two brightest dots (2 laser beams) are overlapping. (May need to use angle adjustors on Mirror #2

4.) Attach 18 mm focal length lens to holder in front of laser adjust position until beam is centered on viewing screen and fringes are visible

Tips:

Counting fringes

1. With fringes visible on viewing screen line up boundary between max. & min.

2. Move micrometer until next boundary is in the same place,
3. Always turn one full rotation before counting, then continue turning in same direction. to avoid backlash
4. Take multiple readings and average them for greater Accuracy

Sources of error

- Backlash - can be minimized for tip 3
- Mirror Travel - mirror movement per turn of micrometer is constant to within 1.5%. mirrors are flat to 1/4 wavelength

Calibrating the Micrometer

1. In Michelson mode turn micrometer knob and count of 25 fringes and record as d'

2. The actual mirror movement is $d = \frac{N\lambda}{2}$ where $N = 25$ and $\lambda = 632.8$ nm
3. multiply micrometer readings by $\frac{d}{d'}$

$d' = 8.0\,\mu m$ $\quad d = \frac{25 \cdot 632.8\,nm}{2} = 7910\,nm = 7.91\,\mu m$

$$\frac{d}{d'} = 0.98875$$

Experiment 1: Introduction to Interferometry

Goal: use interferometer to measure wave length of laser.

Part 1: Wave length

Procedure

1.) Align laser and setup interferometer in Michelson mode
2.) Calibrate micrometer and set to 50 μm from zero turning CCW.
3.) Adjust viewing screen so edge of fringe is at 2 cm marker
4.) Turn micrometer CCW and count 25 fringes & Record difference in μm reading
5.) Repeat for several trials

$\frac{d}{d'} = 0.98875$

Trial	N	d_m (μm)	$d_m \cdot d/d'$ (μm)	$\delta d_{average}/\|d_d\| = 1.5\%$
1	25	8.0	7.91	0.62
2	25	8.0 μm	7.91	0.62
3	30	10.0	9.89	0.65
4	30	10.2	10.1	0.65
5	25	8.0	7.91	0.62
6	20	6.5	6.43	0.60
7	20	6.5	6.43	0.60

$\delta d = \pm 0.5\ \mu m \pm 1.5\%$.

Part 2: Polarization

a) Polarizer between laser and beam splitter
Only effects intensity of fringe pattern not pattern itself

b) Polarizer in front of mirror #1: Affects how close fringes are to each other and moves center of fringe pattern

Polarizer in front of mirror #2: Same

c) Polarizer in front of both mirrors: Rotate ~~mount~~ #1: Fringe lines spread out, blur, move closer, then blur again in a pattern
same for #2

Analysis:

Part 1:

$$\lambda = \frac{2 d_m}{N}$$

Trial	Calibrated d_m	λ μm
1	7.91	0.6328
2	7.91	0.6328
3	9.89	0.65933
4	10.13	0.67533
5	7.91	0.6328
6	6.43	0.643
7	6.43	0.643

Avg λ = 0.6456

$$\delta\lambda = \frac{2}{N}\delta d_m$$

$$\lambda = \frac{2 d_m}{N}$$

$$\Rightarrow \frac{\delta\lambda}{\lambda} = \frac{\delta d_m}{d_m} = 1.5\%$$

Trial	$\delta\lambda$
1	0.0495
2	0.0495
3	0.0519
4	0.0522
5	0.0495
6	0.0477
7	0.0477

$$\delta\lambda_{av} = \frac{\sqrt{(\delta\lambda_1)^2 + (\delta\lambda_2)^2 + \dots}}{7}$$

$$\delta\lambda_{av} = \pm 0.0187\ \mu m$$

$$\cancel{\lambda_{av} = 0.6268\ \mu m \pm 0.0187\ \mu m}$$

$$\lambda_{av} = 0.6456 \pm 0.0187\ \mu m$$

Part 2:

1. Laser is unpolarized. No change in polarization over time
2. No. no noticiable affect from this
3. No cross polarized beams don't interfere

Questions

1.) Because the ~~###~~ beam travels the distance to mirror #1 twice
~~###~~

2.) Reduce uncertainty in our result

3.) N/a Did not try Fabry-Perot

4.) Actual wavelength = $0.6328\,\mu m$
Measured wavelength = $0.6456 \pm 0.0187\,\mu m$

Difference is from uncertainty in micrometer reading and mirror travel

5.) Backlash (can be mitigated by making one full rotation prior to measurement).
Uncertainty in micrometer reading. Increments of $1\,\mu m$ so uncertainty is $\pm 0.5\,\mu m$
Uncertainty in mirror travel. According to manual mirror travel is linear to micrometer reading to within 1.5%. ~~#~~

6.) Miscounting fringes. Improper alignment of fringes to viewing screen

7.) Beams need to have the same polarization to interfere with each other.

Experiment 2: The index of Refraction of air.
Wavelength of light changes when going trough different indices of refraction
For light of specific frequency, the wavelength varies by $\lambda = \frac{\lambda_0}{n}$
where λ_0 is wavelength in a vacuum and n is index of refraction

Procedure:

1.) Setup in Michelson mode
2.) place vacuum cell in between beam splitter & mirror #1
3.) Align vacuum cell to be perpendicular to laser beam
Can tell cell is perpendicular because the reflections from the plates will align
4. Set cell to atmospheric pressure by releasing it fully. Record initial pressure, P_i.
Pump air out of cell and count fringe transitions, N. Record final pressure, P_f

Trial #	P_i: Initial Pressure (in Hg)	P_f: Final Pressure (in Hg)	# fringes N
1	0	16.0	12
2	0	21.0	16
3	0	16.5	12

~~0 in Hg → 101,325 Pa P_f = 101,325 − $P_{measured}$~~

Analysis

~~1 in Hg = 3386.39 Pa~~

1 atm = 29.9213 in Hg   1 in Hg = 2.54 cm Hg

$$\frac{n_i - n_f}{P_i - P_f} = \frac{N\lambda_0}{2d(P_i - P_f)}$$

$d = 3.0$ cm

$\lambda_0 = 632.991$ nm in vacuum (from wikipedia)

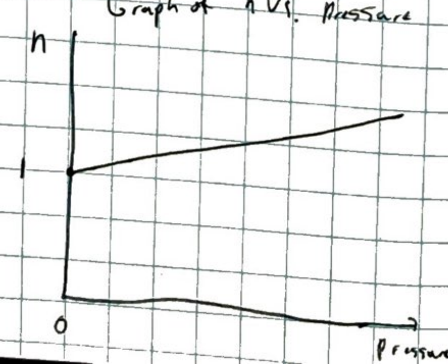
~~Trial~~	~~P_i (Pa)~~	~~P_f (Pa)~~	~~N~~
~~1~~	~~101,325~~	~~47142.76~~	~~12~~
~~2~~	~~101,325~~	~~30210.81~~	~~16~~
~~3~~	~~101,325~~	~~45449.57~~	~~12~~

Trial	P_i (cm Hg)	P_f (cm Hg)	N
1	76	35.359	12
2	76	22.659	16
3	76	34.089	12

Trial	Slope of n vs cm Hg
1	3.115×10^{-6}
2	3.165×10^{-6}
3	3.021×10^{-6}

Avg slope = 3.100×10^{-6}

Graph of n vs. pressure



Questions

1.) $n = P \cdot (3.100 \times 10^{-6}) + 1$ Because when $P = 0 \rightarrow n = 1$

at 1 atm $P = 76$ cm Hg $\longrightarrow n = 1.000236$

2.) measure the index of refraction at different pressures and determine if the relationship is linear

3.) Let the beam that goes to mirror #1 pass through a heated cell at 1 atm and determine the effects on the interference pattern.

Experiment 3: The Index of Refraction of Glass

measure index of refraction of glass by varying length of glass laser beam passes through

Procedure

1. Align lab in Michelson mode
2. Put glass sheet on rotating pointer infront of mirror #1
3. Positioning rotating pointer at 0° and align glass plate so that it is perpendicular to beam.
4. Move rotating lever from 0° to 10° and count the number of Fringes, N, that pass. Record N

$$N = \frac{2 n_a d_a(\theta) + 2 n_g d_g(\theta)}{\lambda_0}$$

Glass thickness = 6.0 mm ± 0.5 mm

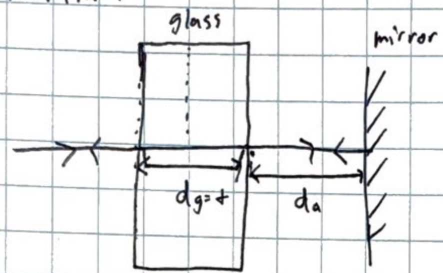
Trial	Angle	Number of fringes, N.	n_g (index of refraction of glass)
1	10°	98	1.508
2	10°	95	1.485
3	10°	101	1.532
4	10°	96	1.492
5	10°	99	1.516

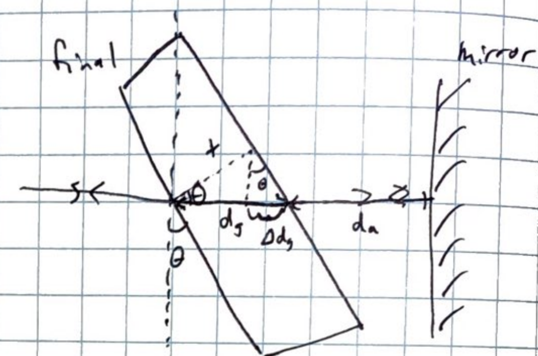
Avg n_g = ~~[illegible]~~ 1.507

Data Analysis

Path length of Laser Beam through glass & air

initial





$$\cos\theta = \frac{t}{d_g} \qquad \cos\theta = \frac{d_g - \Delta d_g}{t}$$

$$\frac{t}{d_g} = \frac{d_g - \Delta d_g}{t}$$

$$\Delta d_g = d_g - \frac{t^2}{d_g} = d_g - t\cos\theta$$

for small angles $\cos\theta \approx 1$ $\quad t \approx d_g$ $\quad \boxed{\Delta d_g = t - t\cos\theta}$

$$\Delta d_a = -\Delta d_g = -t + t\cos\theta$$

$$N = N_f - N_i = \frac{2n_a \Delta d_a(\theta) + 2n_g \Delta d_g(\theta)}{\lambda_0}$$

$$n_g = \frac{(2t - N\lambda_0)(1-\cos\theta)}{2t(1-\cos\theta) - N\lambda_0}$$

$\lambda_0 = 632.991 \times 10^{-9}$ m

$t = 6.0 \times 10^{-3}$ m $\pm 0.5\times1$

Error Analysis

Experiment 2: Index of Refraction of Air

$$\frac{n_i - n_f}{P_i - P_f} = \frac{N\lambda_0}{2d(P_i - P_f)}$$

$d = 3.0\ cm \quad \delta d = \pm 0.1\ cm \Rightarrow d = 0.03\ m \quad \delta d = \pm 0.001\ m$

$\delta \Delta P = \pm 0.5\ in\ Hg = \pm 1.27\ cm\ Hg$

$$\delta m = |m|\sqrt{\left(\frac{\delta d}{d}\right)^2 + \left(\frac{\delta \Delta P}{\Delta P}\right)}$$

Trial	ΔP	m	δm
1	40.641	3.115×10^{-6}	1.42×10^{-7}
2	53.341	3.165×10^{-6}	1.29×10^{-7}
3	41.911	3.021×10^{-6}	$1.36\cancel{08}\times10^{-7}$

$$\delta m_{av} = \frac{\sqrt{(\delta m_1)^2 + (\delta m_2)^2 + (\delta m_3)^2}}{3} = \boxed{7.9\times10^{-8}} \quad \boxed{m = 3.100\times10^{-6} \pm 7.9\times10^{-8}}$$

← $\frac{1}{cm\,Hg}$ units

Experiment 3: Index of Refraction of glass

Use standard deviation of trials

$$\sigma = \sqrt{\frac{1}{5}\sum(x_i - 1.507)^2}$$

Trial	n_g
1	1.508
2	1.485
3	1.532
4	1.492
5	1.516

$\delta n = 0.017$

$$\boxed{n_{glass} = 1.507 \pm 0.017}$$

Results

Exp. 1/ Wavelength of He-Ne Laser

Measured $\lambda = 0.6456 \pm 0.0187\ \mu m$

Actual $\lambda = 0.6328\ \mu m$

Exp. 2/ Refraction index of Air at different Pressures

Eqn $n = p \cdot (3.100 \times 10^{-6} \pm 7.9 \times 10^{-8}\ cmHg^{-1}) + 1$

for atmospheric pressure $p = 76\ cmHg$

$n = 1.000236 \pm 5.604 \times 10^{-6}$

actual $n = 1.000293$

Exp. 3/ Refraction index of glass

Measured $n_{glass} = 1.507 \pm 0.017$

Actual $n \sim 1.5$ depends on the type of glass

window glass $n = 1.52$

Discussion

Overall the experiments seem to be a success. The measured values match the expected results for ~~and~~ the uncertainty in the measurements.

For Exp. 1 on wavelength the averaged value is 0.0128 μm away from the actual value. This is within our value for 1 STD and is 0.685 of our standard deviation ~~this~~ There is a 25.3% chance of a value being ~~~~ within the mean and 0.685 σ for a normal distribution which is reasonable for our data.

Exp. 2/ The slope of our line was $3.100 \times 10^{-6} \pm 7.9 \times 10^{-8}$ cm Hg^{-1}

This gave a value of $1.000236 \pm 5.604 \times 10^{-6}$ for the index of refraction of air which is within 1% of the actual value for the index of refraction which is 1.000293

Exp 3/ The measured value of 1.507 ± 0.017 is within 0.013 of the actual value of 1.52 for window glass this is within our uncertainty and indicated our experiment was accurate.

Not sure what the actual index of refraction is for the glass plate is because different types of glass use different