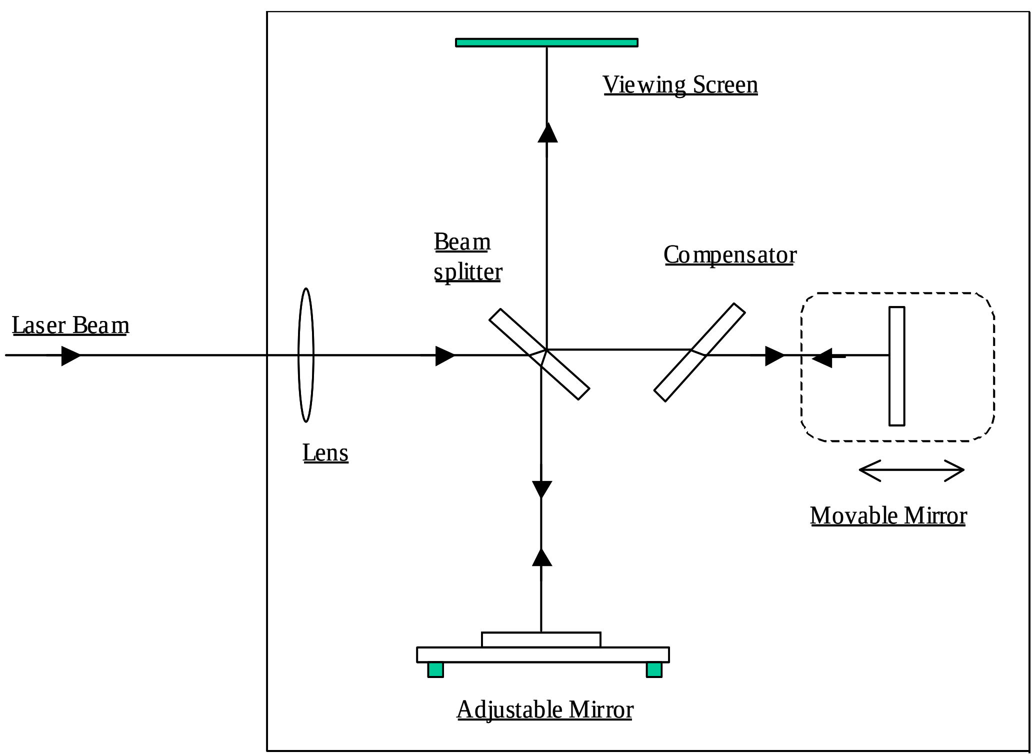
Michelson Interferometer

1) Interference

History:
In 1881, A.A. Michelson designed and built an interferometer to test for the existence of the ether, a hypothesized medium in which light was thought to propagate. The negative result: no “ether wind” could be detected. This was the basis of Einstein’s theory of special relativity—the postulate that the speed of light is constant.
Nowadays, the Michelson Interferometer has become a widely-used instrument for measuring the wavelength of a known light source or for measuring extremely small distances.

Michelson Interferometer:



The laser beam is split in half (amplitude splitting, as opposed to wavefront splitting) by the beam splitter (BS). The beam initially reflected by the BS hits the adjustable mirror and is finally transmitted by the BS; the other beam initially transmitted through the BS is reflected off the movable mirror and is finally reflected by the BS. These two beams interfere. The 18-mm lens enlarges the beam, making the interference pattern easier to see. The compensator makes the path to the movable mirror more similar to the other by compensating for the two extra passes through the beamsplitter made by the other beam.

1) Alignment of the set-up

Put all the components into place as shown in the diagram above.
USE GLOVES: NO FINGERPRINTS ON OPTICAL COMPONENTS!

Mount the diode laser on short optical rail.

Mount Michelson Interferometer:
Prop up the Michelson Interferometer so that

a) it is at the same height as the laser beam
b) it is roughly level

Adjust the diode laser so that

a) the beam hits the BS and fixed & adjustable mirror (centered)
b) the reflection from the fixed mirror goes back onto the beam on the BS

Insert the 18-mm lens and move the lens around so that you see a beam on the viewing screen. Then turn the knobs of adjusting mirror (to minimize # of visible fringes) and test the moving mirror by turning the micrometer screw.

2) Measurement of laser wavelength

Check if you can find the position of minimum “optical path length difference”. Rotate the micrometer screw for large distances and see how the pattern changes (rings should get smaller or wider). You may have to loosen and reset the fixed mirror, then realign. In the minimum, the rings should be bigger than the viewing screen.

3) Measurement of laser wavelength

If you move the mirror by distance d, the optical path difference between the two interfering laser beams is changed by $\Delta = 2d$.
From the interference condition for minima or maxima: $\Delta = m\lambda = 2d$

Thus, by counting the number of interference maxima (or minima), m, while changing the mirror position over a known distance d, you can find the wavelength:

Perform at least 3 trials; m should be around 30; let different people count!

Trials	# minima m	Distance d **(see calibration!)**	wavelength
1			
2			
3			

Your average value of the wavelength is:

<u>Question:</u> Compare your value with the accepted wave length of the diode laser: 650nm. Mention some sources of error (at least 4) and number them according to their likelihood.

3) The Index of Refraction of Air

Introduction:
They are two ways to change the fringe pattern of a Michelson-Interferometer:

a) change the *difference* between the two physical path lengths
b) change the medium through which one of the beams travels

We will use the second case to measure the index of refraction of air.
In principle, the index of refraction of a gas depends on its composition, pressure and temperature. For low gas pressures (as is the case with atmospheric pressure) the index of refraction varies linearly with pressure.
We will decrease the pressure and see how the index of refraction changes. At zero pressure (i.e, vacuum) we know $n = 1$.

Demo: Take a lighter or a match and hold it close to one of the beam paths. Through convection, the air will heat up in one beam path, resulting in a change of pressure and in the observed interference pattern.

Theory:
For light of a specific frequency, the wavelength λ varies according to: $\boldsymbol{\lambda = \lambda_0 / n}$, where $\boldsymbol{\lambda_0}$ is the wavelength in vacuum. The number of waves (N) that fit in a cell of length l filled with gas (air) of refractive index n is: $\boldsymbol{N = l / \lambda = n\, l / \lambda_0}$.
If we change n (by pumping out the air) N also changes, and $\boldsymbol{\Delta N = \Delta n * l / \lambda_0}$.
One way to understand this is that when n changes the OPD also changes, thus we will observe a change in the fringe pattern. In this lab you will measure the change in the number of fringes, Δm, which is related to ΔN by $\Delta m = 2\Delta N$, because the light travels twice through the cell.
You will measure Δm as a function of pressure, p: reduce the pressure from atmospheric pressure to vacuum by pumping out the chamber. By counting the resulting Δm and knowing $l = 3cm$ and $\lambda = 650nm$ (for red light), we can infer the change in index, Δn.
Extrapolating to zero-pressure, you know that n=1 (vacuum). Now you should be able to derive the refractive index of air at atmospheric pressure.

Experimental Set-up:
Remove the compensator (GLOVES ON)
Realign the interference pattern
Insert the holder with the arm in front of the movable mirror and put the gas cell inside the holder.
Connect tube to gas cell and to hand-held vacuum pump
Realign the interference pattern
Rotate the gas cell slowly; you will see that the fringes move. When the cell is parallel to the laser beam, the fringes stop moving before they turn around. Hold your cell at this position (manually).

Measurement:
Slowly pump down the cell (step-by-step), in between taking readings of the pressure (in inches Hg) and total number of minima counted (Δm).
Then allow air back to the cell.
Repeat measurement at least 3 times (each lab partner should try the measurement)

Analysis:
For each value of Δm calculate the corresponding Δn.
Plot Δn versus pressure change (in cm Hg). Note that the pressure on the gauge is in "inches Hg" below atmospheric pressure; a pressure reading of 76cm Hg equals a pressure of absolute zero (vacuum), while a reading of zero refers to atmospheric pressure of 76cm Hg).
Make a trend line fit to find the slope.
Knowing the slope and the *n*-value at zero pressure, calculate *n* for atmospheric pressure.

Data:

First Trial		Second Trial		Third Trial	
Δm	Δp	Δm	Δp	Δm	Δp

Our experimentally derived value of the refractive index of air is: n_{air} =

Questions:
1) Compare your average value with accepted value of $n_{air,theo} = 1.000263$. What are possible sources of error? How could one improve the measurement?

2) How would you design an experiment to test the temperature dependence of the index of refraction?