Experiment 2: The Index of Refraction of Air

EQUIPMENT NEEDED:

– Basic Interferometer (OS-9255A)
– Laser (OS-9171)
– Laser Alignment Bench (OS-9172)
– Interferometer Accessories (OS-9256A)
  Rotational pointer, Vacuum cell, Vacuum pump

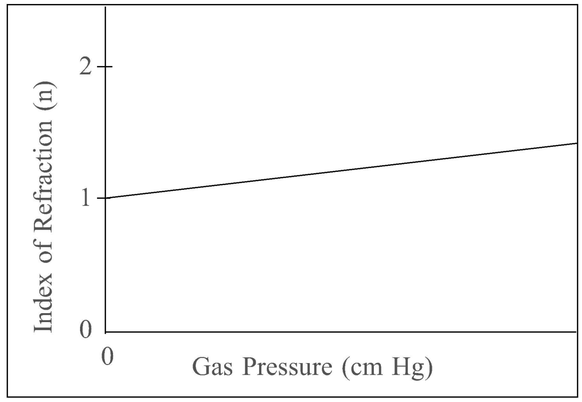

Figure 2.1. Index of Refraction versus Gas Pressure

Introduction

In the Michelson interferometer, the characteristics of the fringe pattern depend on the phase relationships between the two interfering beams. There are two ways to change the phase relationships. One way is to change the distance traveled by one or both beams (by moving the movable mirror, for example). Another way is to change the medium through which one or both of the beams pass. Either method will influence the interference pattern. In this experiment you will use the second method to measure the index of refraction for air.

For light of a specific frequency, the wavelength λ varies according to the formula:

$$\lambda = \lambda_o/n;$$

where λ_o is the wavelength of the light in a vacuum, and n is the index of refraction for the material in which the light is propagating. For reasonably low pressures, the index of refraction for a gas varies linearly with the gas pressure. Of course for a vacuum, where the pressure is zero, the index of refraction is exactly 1. A graph of index of refraction versus pressure for a gas is shown in Figure 2.1. By experimentally determining the slope, the index of refraction of air can be determined at various pressures.

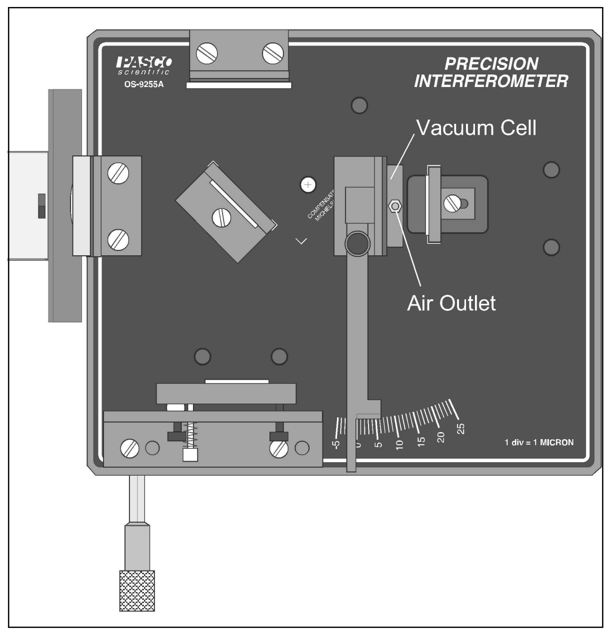

Figure 2.2. Equipment Setup

Procedure

1. Align the laser and interferometer in the Michelson mode. See *Setup and Operation*.
2. Place the rotational pointer between the movable mirror and the beam-splitter (see Figure 2.2). Attach the vacuum cell to its magnetic backing and push the air hose of the vacuum pump over the air outlet hole of the cell. Adjust the alignment of the fixed mirror as needed so the center of the interference pattern is clearly visible on the viewing screen. (The fringe pattern will be somewhat distorted by irregularities in the glass end-plates of the vacuum cell. This is not a problem.)
3. For accurate measurements, the end-plates of the vacuum cell must be perpendicular to the laser beam. Rotate the cell and observe the fringes. Based on your observations, how can you be sure that the vacuum cell is properly aligned?

4. Be sure that the air in the vacuum cell is at atmospheric pressure. If you are using the OS-8502 Hand-Held Vacuum Pump, this is accomplished by flipping the vacuum release toggle switch.
5. Record $\mathbf{P_i}$, the initial reading on the vacuum pump gauge. Slowly pump out the air in the vacuum cell. As you do this, count **N**, the number of fringe transitions that occur. When you're done, record **N** and also $\mathbf{P_f}$, the final reading on the vacuum gauge. (Some people prefer to begin with the vacuum cell evacuated, then count fringes as they let the air slowly out. Use whichever method is easier for you.)

> ➤ **NOTE:** Most vacuum gauges measure pressure with respect to atmospheric pressure (i.e., 34 cm Hg means that the pressure is 34 cm Hg below atmospheric pressure, which is ~ 76 cm Hg). The actual pressure inside the cell is:
>
> $$\mathbf{P}_{\text{absolute}} = \mathbf{P}_{\text{atmospheric}} - \mathbf{P}_{\text{gauge}}$$

Analyzing Your Data

As the laser beam passes back and forth between the beam-splitter and the movable mirror, it passes twice through the vacuum cell. Outside the cell the optical path lengths of the two interferometer beams do not change throughout the experiment. Inside the cell, however, the wavelength of the light gets longer as the pressure is reduced.

Suppose that originally the cell length, **d**, was 10 wavelengths long (of course, it's much longer). As you pump out the cell, the wavelength increases until, at some point, the cell is only 9-1/2 wavelengths long. Since the laser beam passes twice through the cell, the light now goes through one less oscillation within the cell. This has the same effect on the interference pattern as when the movable mirror is moved toward the beam-splitter by 1/2 wavelength. A single fringe transition will have occurred.

Originally there are $\mathbf{N_i} = 2\mathbf{d}/\boldsymbol{\lambda}_i$ wavelengths of light within the cell (counting both passes of the laser beam). At the final pressure there are $\mathbf{N_f} = 2\mathbf{d}/\boldsymbol{\lambda}_f$ wavelengths within the cell. The difference between these values, $\mathbf{N_i} - \mathbf{N_f}$, is just **N**, the number of fringes you counted as you evacuated the cell. Therefore: $\mathbf{N} = 2\mathbf{d}/\boldsymbol{\lambda}_i - 2\mathbf{d}/\boldsymbol{\lambda}_f$.

However, $\boldsymbol{\lambda}_i = \boldsymbol{\lambda}_0/\mathbf{n}_i$ and $\boldsymbol{\lambda}_f = \boldsymbol{\lambda}_0/\mathbf{n}_f$; where $\mathbf{n}_i$ and $\mathbf{n}_f$ are the initial and final values for the index of refraction of the air inside the cell. Therefore $\mathbf{N} = 2\mathbf{d}(\mathbf{n}_i - \mathbf{n}_f)/\boldsymbol{\lambda}_0$; so that $\mathbf{n}_i - \mathbf{n}_f = \mathbf{N}\boldsymbol{\lambda}_0/2\text{d}$. The slope of the n vs pressure graph is therefore:

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

where $\mathbf{P}_i$ = the initial air pressure; $\mathbf{P}_f$ = the final air pressure; $\mathbf{n}_i$ = the index of refraction of air at pressure $\mathbf{P}_i$; $\mathbf{n}_f$ = the index of refraction of air at pressure $\mathbf{P}_f$; **N** = the number of fringe transitions counted during evacuation; $\boldsymbol{\lambda}_0$ = the wavelength of the laser light in vacuum (see your instructor);
d = the length of the vacuum cell (3.0 cm).

1. Calculate the slope of the n vs pressure graph for air.
2. On a separate piece of paper, draw the n vs pressure graph.

Questions

1. From your graph, what is $\mathbf{n}_{\text{atm}}$, the index of refraction for air at a pressure of 1 atmosphere (76 cm Hg).
2. In this experiment, a linear relationship between pressure and index of refraction was assumed. How might you test that assumption?
3. The index of refraction for a gas depends on temperature as well as pressure. Describe an experiment that would determine the temperature dependence of the index of refraction for air.