SI 2.1 Michelson interferometer (Indiana University)

INDIANA UNIVERSITY, DEPARTMENT OF PHYSICS, P309 LABORATORY

Laboratory #40: Michelson Interferometer, The Refractive Index of a Gas

Goal: Measure the refractive index of gases using a Michelson interferometer

Equipment: Michelson interferometer, gas cell, compensator, absolute pressure gauge, cylinders with various gases, vacuum pump.

(A) Experimental setup:

The Michelson interferometer is illustrated in Fig. 1. A bundle of light from the light source falls on the beam splitter, which on its rear surface has a reflecting coating. The beam splitter divides the light into two beams, one transmitted toward the fixed mirror M2, the other reflected toward the moveable mirror M1. The two mirrors return the light to the reflecting surface where they recombine and proceed toward the observer, where interference is observed.

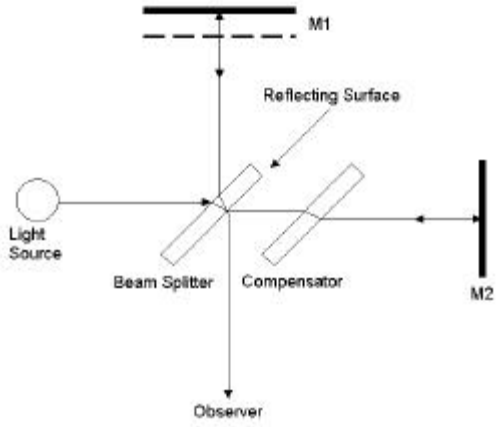

Figure 1: Michelson Interferometer

The interferometer must be aligned before it can be used. Alignment can be made with adjustment screws on the mount of mirror M2, which allow to tilt it, and with the main micrometer screw which moves mirror M1 a directly measured distance perpendicular to its plane. *Note that there is a 5:1 gain caused by the lever*.
The *first step* is to set the length of the moveable arm equal to that of the fixed arm. This is done by measuring with a ruler the distance from the center of the beamsplitter to the center of each mirror.

The *second step* is to align the mirrors M1 and M2 accurately perpendicular to one another. Illuminate the beamsplitter with a quasi-monochromatic source (usually a ground glass screen illuminated by a mercury source and a green filter). Look into the interferometer. Two images of the pin inserted between the light source and the beamsplitter will be visible, if the two mirrors are misaligned. A slight adjustment of the screws on mirror M2 aligns this mirror till the two images coincide. When this is done, interference fringes will appear across the field of view.
The *third step* is to use the tilt controls to bring the center of the fringes into the center of the field of view.
Finally the position of the moveable mirror is adjusted so that the path difference is close to zero. As the path length difference approaches zero, the circular fringes become larger and widely separated, the contrast between blackness and maximum brightness slowly disappears, and it will be quite difficult to discern the fringe pattern, especially when the central fringe covers the whole field of view (see top row of Fig.2). *Note that the length difference becomes less as the fringes move inward toward the center of the fringe pattern. When the direction of the fringe pattern movement inverses, zero path difference has been passed*. At this point, white light is substituted for the quasi-monochromatic source, and the final but also most difficult adjustment of the position of mirror M1 is made until the center of the field of view will be dark. The optical path lengths of the two arms are now exactly equal and the entire spectrum of wavelengths is in phase.

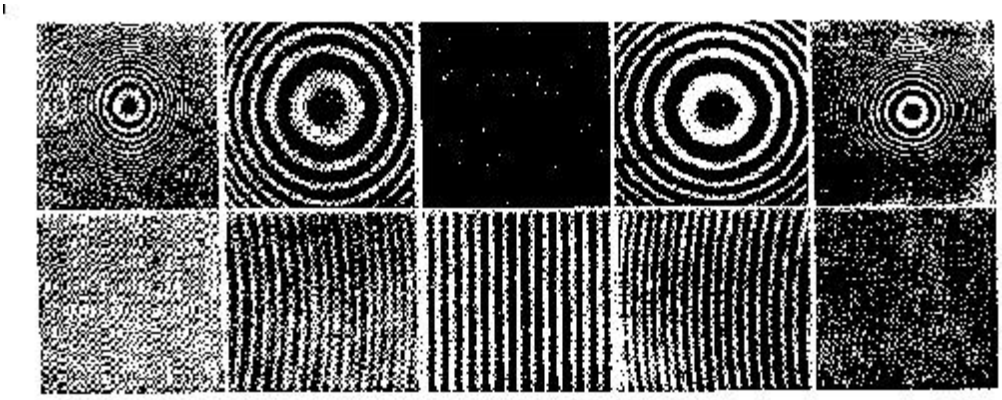

Figure 2: Appearance of circular fringes (upper row) and localized fringes (lower row) in the Michelson interferometer. Path difference increases outward, in both directions, from the center.

A comparatively easier method is to use localized fringes in the field of view. Localized fringes can be obtained by tilting mirror M2 slightly away from the position where its surface is perpendicular to that of the plane of mirror M1. Then M1 and M2 are inclined at a small angle. The observed fringes are slightly curved (see bottom row of Fig. 2). As the path length difference decreases toward zero, these localized fringes become straighter and the curve in the opposite direction as the path length difference increases beyond the region where the planes of M1 and M2 intersect (the image of M2 near M1). The setting where the localized fringes become straight and few in numbers correspond to zero or near zero path length difference. At this point the quasi-monochromatic light source is

replaced by white light. A slight adjustment of the moveable mirror places the dark fringe of zero path length difference in the center of the field of view. The central dark fringe is bordered on either side by 4 to 8 colored fringes.
Repeat these alignment procedures till you have mastered them and you are able to produce various forms of fringes at will.

(B) Measuring the Index of Refraction of a Gas:

Connect one of the three inlets to the gas cell to the manometer, the second via a valve to the vacuum pump and the third via a needle valve to a gas cylinder. *When a gas cylinder is being used, special care should exercised to see that no excessive pressure does build up in the apparatus.*
Adjust the interferometer for zero path length difference using localized fringes. Switch back to the green quasi-monochromatic mercury light source. The gas cell is then evacuated as completely as possible and the valve closed to isolate the pump. Air (or gas) is the admitted through the needle valve, the rate being adjusted until the fringes are moving at a conveniently slow rate of about 5 fringes per minute. Place a thermometer adjacent to the cell in order to record its temperature.
A suggested procedure is for one observer to count fringes aloud while the other reads the manometer at, say, every 5th fringe and records the results. Repeat the whole procedure a number of times, since random errors enter into both the manometer reading and fringe counting.
Plot the manometer reading *P* versus the fringe number *N*. This should be a straight line. From this line the slope *dN/dP* is obtained. The index of refraction n_0 of air (or gas) at N.T.P. can be calculated from the following equation, assuming that the ideal gas law holds:

$$(n_0 - 1) = \left(\frac{dN}{dP}\right)\left(\frac{l}{2\ell}\right)\left(\frac{760 \cdot T}{273}\right)$$

Here l is the wavelength of the light used, ℓ the length of the gas cell, and *T* the temperature in K.
The cell length should be measured by whatever suitable means is available. It cannot be assumed that the glass windows come into contact with the metal body of the cell.

The following points should be carefully studied:
1. Correction of manometer reading for temperature, etc.
2. Deviation from the ideal gas laws assumed in the above equation.
3. Change in effective cell length due to atmospheric pressure when cell is partially evacuated.
4. Influence of the relative humidity of the air.
5. Drift in the interferometer during observations.