Experiment 2

The Michelson Interferometer

2.1 Outline of Theory

In the Michelson Interferometer (Figure 2.1), light from an extended source S is split into two beams of equal intensity by the lightly silvered back surface of the beam splitter G_1.

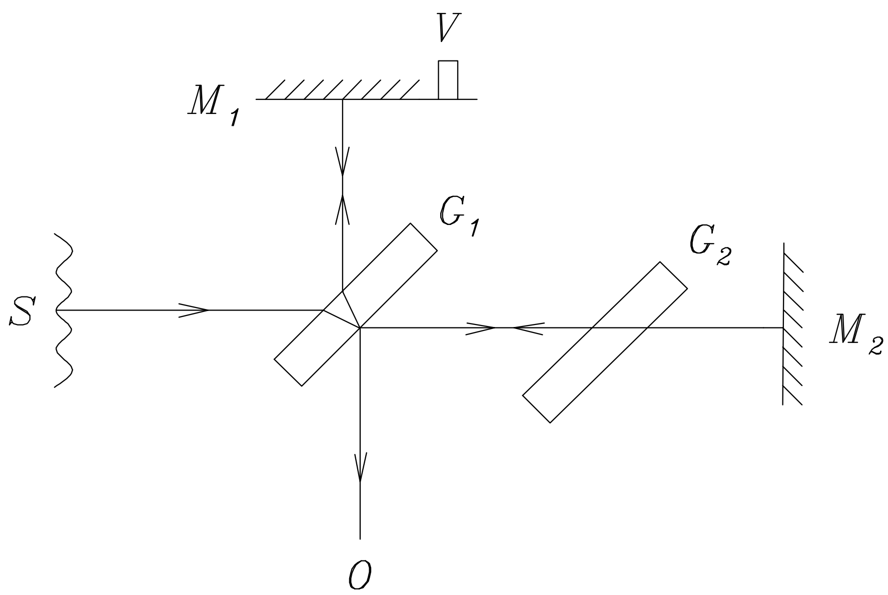


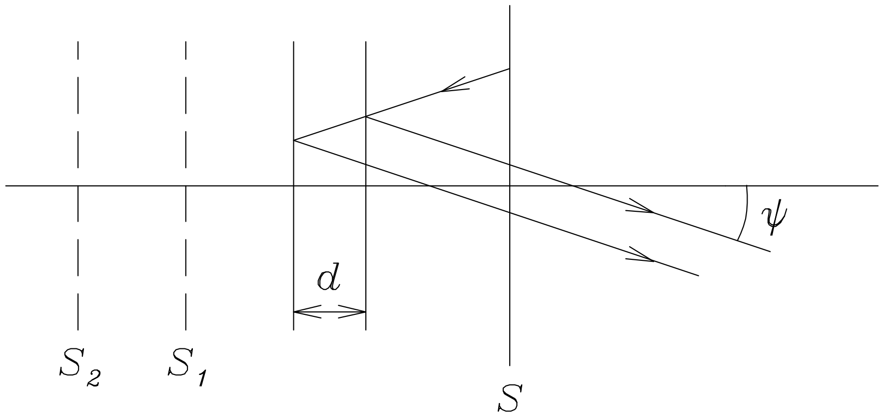
Figure 2.1: The Michelson Interferometer – Theoretical Representation

One beam is reflected from the movable mirror M_1, whose position is determined by the micrometer screw V. The other beam passes through the compensator plate G_2 (equal in optical thickness to G_1), and is reflected from the adjustable mirror M_2. This beam is again reflected by G_1, and the interference phenomena between the two beams can be observed in the direction O.

Fringes of Equal Inclination

When M_2 is adjusted perpendicular to M_1, then its image M_2', formed by reflection in G_1 is parallel to M_1 and separated by a distance $d = M_2G_1 - M_1G_1$. The source plane S gives, by reflection in G_1, M_1 and M_2, two virtual source planes S_1 and S_2 separated by $2d$.

The path difference Δ between two rays, coming from P on S, at an angle ψ with the axis perpendicular M_1, is then



$$\Delta = 2d\cos\psi$$

The phase difference between these two rays is then

$$\delta = \left(\frac{2\pi}{\lambda}\right) 2d\cos\psi - \pi$$

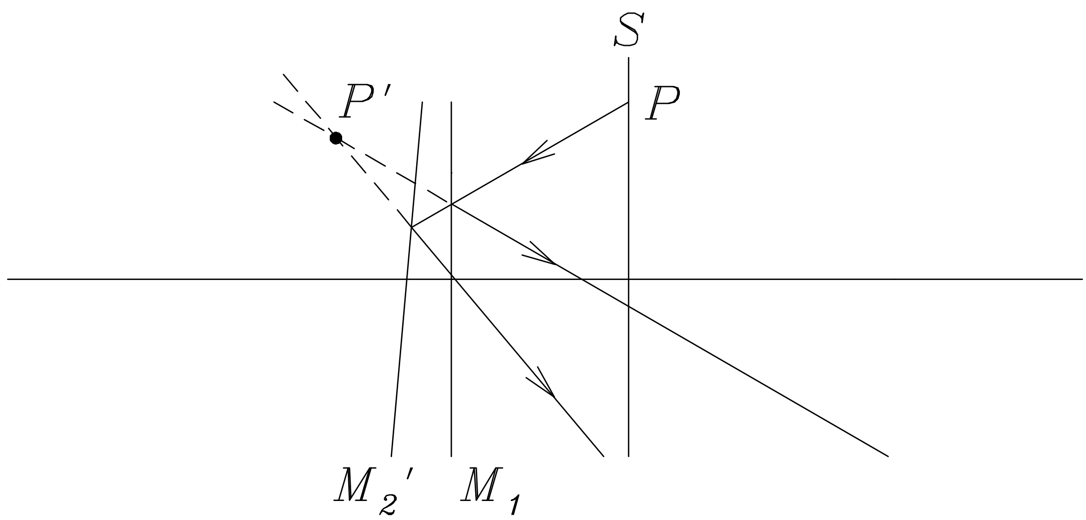
since the returning beam from M_2 suffers a phase change π on reflection from G_1. Looking in the direction G_1M_1, an observer will therefore see a set of circular fringes. The spacing of these fringes of equal inclination will depend on the value of d. The central portion of the field will be dark for

$$d = \frac{m\lambda}{2},\ m = 0, \pm 1, \pm 2, \ldots$$

These fringes remain visible for relatively large values of d, depending on the monochromaticity of the source S.

Fringes of Equal Thickness

When M_2 is not exactly perpendicular to M_1, and d is small, then the space between M_1 and M_2' is a thin wedge. The two rays from P now seem to diverge from a point P' near M_1.



For various positions of P on S, the point P' stays always close to M_1 and the path difference between the two rays is constant. Looking at M_1 we will see a set of straight fringes, parallel to the wedge edge. These fringes of equal thickness connect points of equal air thickness in the wedge formed by M_1 and M_2'. If d increases, the fringes will become curved, and for large d no fringes can be seen.

White Light Fringes

If S is a white light source, then fringes can only be seen for very small values of d. For $d = 0$ the central fringe is black, the neighbouring fringes are strongly coloured, and about 5-10 fringes can be seen. If d is larger than a few wavelengths, then no fringes at all can be seen with a white light source.

2.2 Procedure

2.2.1 Alignment of M_2

1. Illuminate the diffusing screen S with the mercury lamp, using the green filter to obtain monochromatic light with $\lambda = 5461$ Å.

2. Place the small pointer on the screen S. Looking into the interferometer from O, you will see two images of this pointer, formed by reflection in M_1 and M_2.

3. Adjust M_2 until these images coincide. Circular fringes will then be seen behind M_1.

2.2.2 Calibration of the screw V in terms of λ

Rotating the micrometer screw V displaces M_1 in the direction of G_1M_1. Displacing M_1 over a distance $\lambda/2$ brings a new fringe into the field of view (the order of interference changes from m to $m+1$).

1. Measure the rotation of V necessary to change m by fifty, and repeat this measurement five times.

You can now calculate how far one full revolution of V displaces M_1, i.e. you have calibrated the effective pitch of V in terms of λ.

2.2.3 Measurement of the refractive index

1. Now that V is calibrated, make the distance G_1M_1 closely equal to G_1M_2, by rotating V until you observe only one or two circular fringes.

2. Adjust M_2 until fringes of equal thickness are visible.

3. Illuminate S with white light and very carefully adjust V until coloured (straight) fringes are observed. If the black fringe is in the centre of the field of view, then d is exactly zero. Let the reading of V in this position be q_1.

4. Place a microscope cover glass carefully against M_2 so that it covers the lower half of M_2. The optical path length of that part of the beam going through the cover glass to and from M_2 has now increased by $2(n-1)\ell$, where n is the refractive index and ℓ the thickness of the cover glass.

5. Increase the optical path $G_1M_1G_1$ by an equal amount by displacing M_1 with the help of V so that the coloured fringes will be seen in the lower half of the field of view.

6. Let the reading of V be q_2 when the black fringe, as seen through the cover glass, is in the center of the field of view.

7. From q_1 and q_2 (each measured five times), and the calibration of V obtained in section 2.2.2, you can calculate $n\ell$.
8. Measure ℓ five times with a micrometer, and calculate n (assuming n_{air} equal to 1.000).
9. Calculate the experimental error in your value of n.

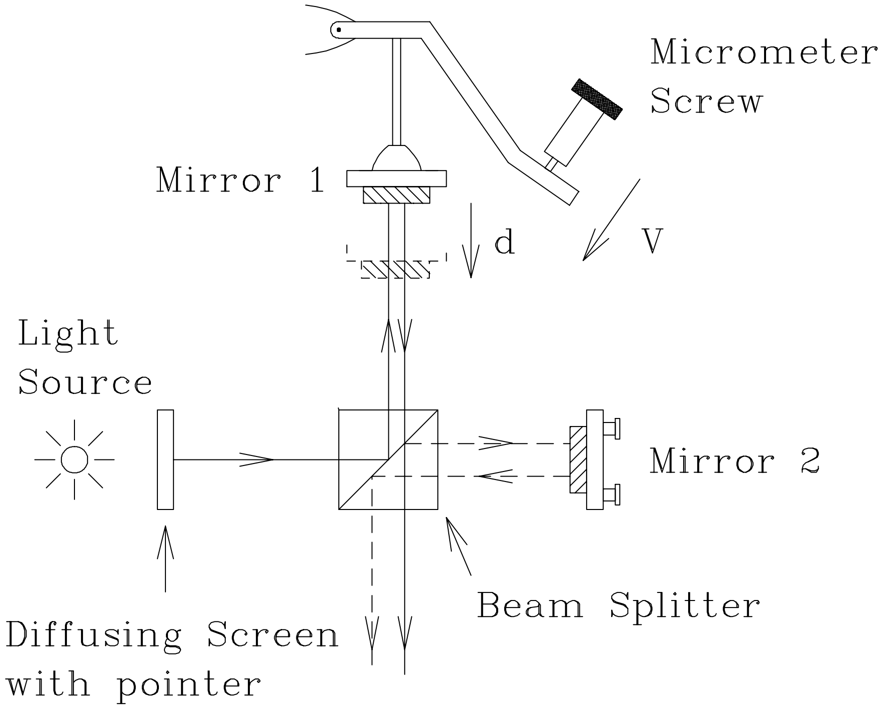


Figure 2.2: The Michelson Interferometer – Physical Representation