PHYSICS EXPERIMENT

Michelson interferometer

DEMONSTRATE AND INVESTIGATE HOW A MICHELSON INTERFEROMETER WORKS.

- Determine the wavelength of a laser.
- Determine the refractive index of air as a function of pressure.

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BASIC PRINCIPLES

The Michelson interferometer was invented by *A. A. Michelson* originally to demonstrate whether the Earth could be observed to be in motion through an ether in which light was once thought to propagate. His design (see Fig. 1) has nevertheless proved crucial for making interferometric measurements, e.g. of changes in length, thickness of layers or refractive indices. A divergent light beam is split into two by a half-silvered mirror and the two resulting beams travel along differing paths. They are then reflected back on themselves and recombined so that interference patterns can be viewed on a screen. The resulting pattern is highly sensitive to any differences in the optical paths covered by the split beams. If the refractive index remains constant the degree of change in the geometric paths can be calculated, e.g. changes in size of various materials due to thermal expansion. If by contrast the geometry is maintained, then refractive indices or changes in them due to pressure, temperature or density variations may be determined.

Depending on whether the optical paths are increased or decreased in length, interference lines may appear or disappear in the centre of the pattern. The relationship between the change Δs in the optical paths and the wavelength λ is as follows

(1) $2 \cdot \Delta s = z \cdot \lambda$,

The number z is a positive or negative integer corresponding to the number of interference lines appearing or disappearing on the screen.

If the wavelength of light in air is to be measured by moving one of the two mirrors by a carefully defined distance Δx by means of a fine adjustment mechanism, the refractive index can be assumed to be n = 1 to a good approximation. The change in the optical path is thus:

(2) $\Delta s = \Delta x$

The situation is different if an evacuated chamber of length d is inserted into only one of the split beams. By allowing air to pass into the vessel until the pressure rises to a value p, the optical path changes as follows

(3) $\Delta s = (n(p) - 1) \cdot d = A \cdot p \cdot d$,

This is because the refractive index of air at constant temperature varies with pressure in a fashion that can be represented in the following form:

(4) $n(p) = 1 + A \cdot p$.

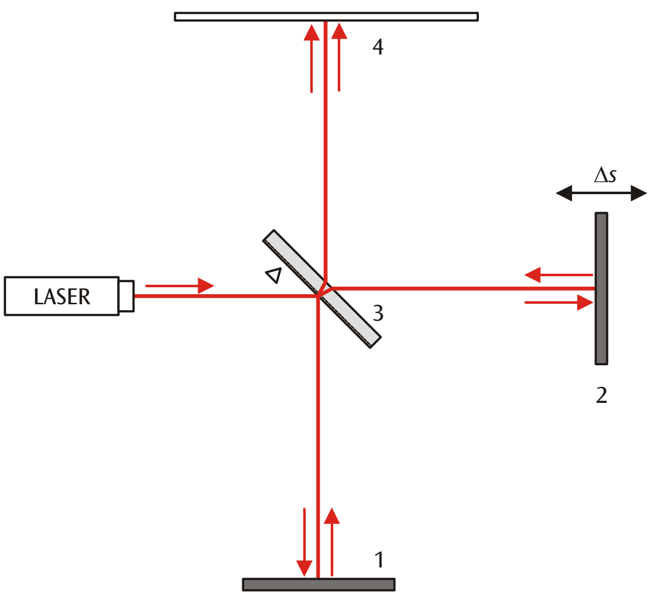

Fig.1: Optical paths in a Michelson interferometer
1: fixed mirror, 2: moveable mirror,
3: beam splitter, 4: screen

LIST OF APPARATUS

1	Interferometer	U10350
1	Accessory Set for the Interferometer	U10351
1	He-Ne Laser	U21840
1	Vacuum Hand Pump	U20500
1	Tubing, Silicone 6 mm	U10146

SET-UP

Fig. 2: Michelson interferometer

Note: The height of the light beam above the baseplate must be 60 – 62 mm.

- Place the interferometer on a stable and firm table with its base as accurately horizontal as possible.
- Mount the laser on the laser support using the hexagonal adjusting screw and position it facing as directly as possible into the beam-diverging lens.
- Remove the fixed mirror and the beam splitter.
- Loosen the knurled screw of the diverging lens and swing the lens out of the path of the beam.
- Adjust the position of the laser so that its beam falls on the centre of the moveable mirror and the reflected beam falls centrally on the laser.
- Swing the diverging lens back into the beam path and correct the beam path so that it also falls on the centre of the lens.
- Swing the diverging lens out of the path of the beam again.
- Mount the fixed mirror and, using the adjusting screws, set it so that the distance between the mirror mounting plate and the actual mirror support is about 5-6 mm and is uniform all around.
- Mount the beam splitter with its half-silvered side (marked with a triangle) towards the near left corner (between the laser and the fixed mirror), and adjust it so that the two brightest points that are visible on the observation screen lie as nearly as possible on a vertical line.
- Adjust the fixed mirror so that these two brightest points on the screen are made to coincide exactly.
- Swing the diverging lens back into the beam, adjust it so that the brightest part of the image is at the centre of the screen, and fix it in position with the screw.
- Tilt the screen slightly from the vertical position so that the observer sees a bright and clear image.
- Readjust the fixed mirror so as to obtain interference rings centred at the middle of the screen.

EXPERIMENT PROCEDURE

Determination of the wavelength of the laser:

Note: Try to avoid exhaled air drifting into the path of the beam during the measurements, as differences in the density of the air are sufficient to cause movements of the interference rings.

- First turn the micrometer screw about 25 mm in the backwards direction (anticlockwise), then slowly turn it clockwise to the zero position $x(0) = 20.00$ mm.
- Next, turn the micrometer screw further in the clockwise direction until 30 complete new interference rings appear.
- Read this position $x(30)$ on the micrometer screw and record the result.

Determination of the refractive index of air as a function of the air pressure:

- Rotate the beam splitter so that the half-silvered side faces towards the rear right corner.
- Place the vacuum cell in the right-hand partial beam (see Fig. 3).
- Connect the vacuum pump to the vacuum cell.
- Readjust the moveable mirror slightly to keep the interference rings in the middle of the screen.
- Slowly pump out the vacuum cell and count the number z of rings that disappear.
- Record the pressure p in regular increments and the corresponding number z.

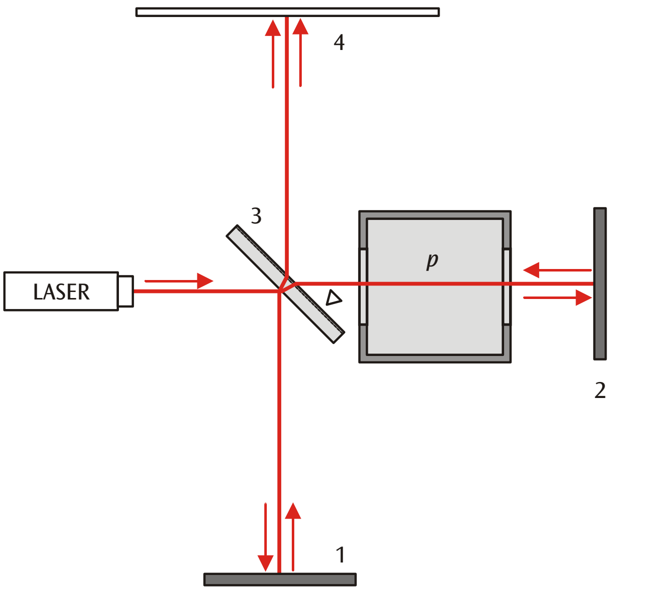

Fig.3: Vacuum chamber in the beam path of the Michelson interferometer

SAMPLE MEASUREMENTS

Determination of the wavelength of the laser:

z = 30, $x(0)$ = 15.98 mm, $x(30)$ = 7.77 mm,
movement reduction ratio 1 : 830

Determination of the refractive index of air as a function of the air pressure:

Table 1: Number of new interference rings z observed during pumping out a vacuum cell as a function of the pressure difference Δp

Δp / hPa	p / hPa	z
220	780	10
420	580	16.5
550	450	21.5
650	350	25
720	280	28
780	220	30
800	200	31
820	180	32
840	160	33

EVALUATION

Determination of the wavelength of the laser:

Solving equations (1) and (2) for wavelength gives an equation for the wavelength that depends on the change in position of the mirror:

$$\lambda = \frac{2 \cdot \Delta x}{z}$$

The distance moved by the mirror to produce 30 interference rings is:

$$\Delta x = \frac{x(0) - x(30)}{830} = 9{,}9\ \mu\text{m}$$

Therefore:

$$\lambda = \frac{2 \cdot \Delta x}{z} = 660\ \text{nm}$$

Value from published tables: $\lambda_{\text{HeNe}} = 632.8$ nm

Determination of the refractive index of air as a function of the air pressure:

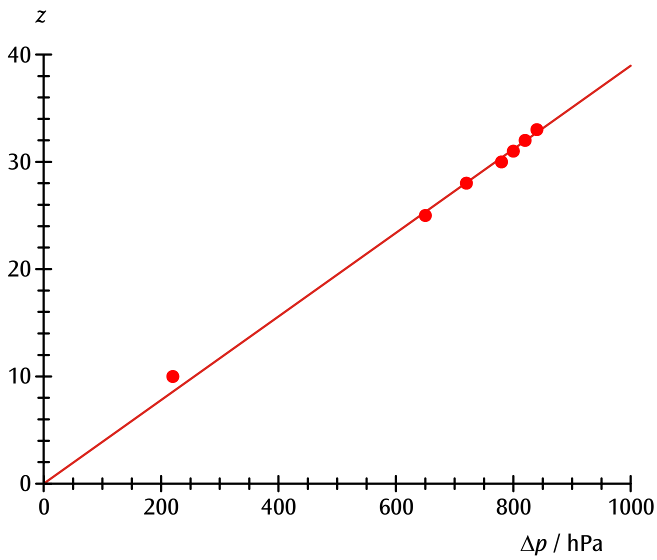

Fig. 4: Number of new interference rings as a function of the pressure difference

In Figure 4 the number of new interference rings z produced by pumping out the vacuum cell is plotted as a function of the pressure difference Δp. Within the limits of accuracy of the experiment, the data points lie on a straight line through the origin with a gradient a, which is:

$$a = \frac{2 \cdot A \cdot d}{\lambda} = 0.039 \frac{1}{\text{hPa}}$$

Therefore:

$$A = \frac{a \cdot \lambda}{2 \cdot d} = 0.30 \cdot 10^{-6} \frac{1}{\text{hPa}}$$

Thus the refractive index of air at normal pressure is:

$$n = 1 + A \cdot 1000\ \text{hPa} = 1.0003$$