Determining the wavelength of the light of an He-Ne laser using a Michelson interferometer – Setup on the optical bench

Experiment Objectives

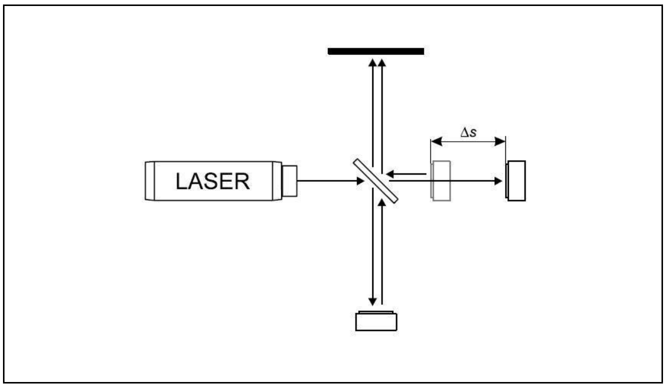
- Setup of the Michelson interferometer
- Observation of the changes in the interference pattern when shifting an interferometer's mirror
- Determining the wavelength of the laser's light from the mirror's displacement.

Fundamentals

Interferometry is a very precise and sensitive measuring method to determine length variation, layer thickness, refractive index, and wavelength, for example. The Michelson interferometer is a type of two-beam interferometer.

The interferometric measurements with this type of interferometer rely on the following principle:

A beam splitter (semi permeable mirror) splits the coherent light beam coming from a suitable light source into two parts. The beamlets take different paths, are reflected back, are then reunited and follow the same path again. An interference pattern emerges from the overlay of the light waves. If the optical path length of one of these beamlets then changes, i.e. the product's refractive index and geometrical path change, then it experiences a phase shift compared to the unchanged beam.
This changes the interference pattern, which helps to find the change in refractive index or geometrical path, if the other variable remains constant.
So differences in the geometrical path can be determined for a constant refractive index, e.g. changes in length of the materials due to heat or to the influence of electric or magnetic fields. If instead the geometrical path remains constant, then refractive indices or even parameters and actions that modify the refractive index can be determined. Such variables can be changes in pressure, temperature or density.



The measurement of the laser light's wavelength relies on shifting by fine adjustment mechanism one of the plane mirrors by a precise distance Δ*s*, which changes the optical path length of the affected beamlet. During this shift, the interference fringes move on the observation screen. The evaluation relies on counting either the maxima or the minima of intensity that pass by a defined point on the observation screen while shifting the plane mirror is.

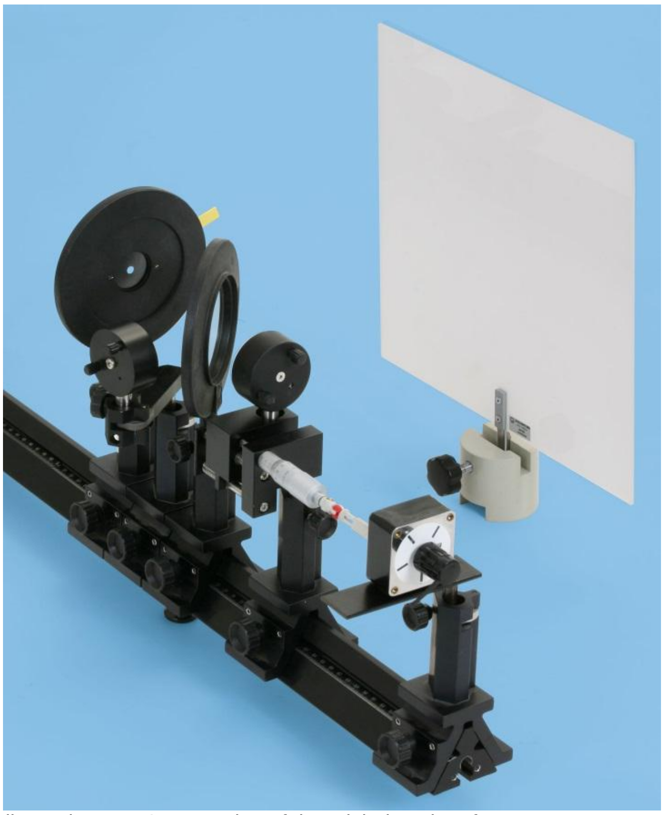


Illustration 1: Construction of the Michelson interferometer on the optical bench

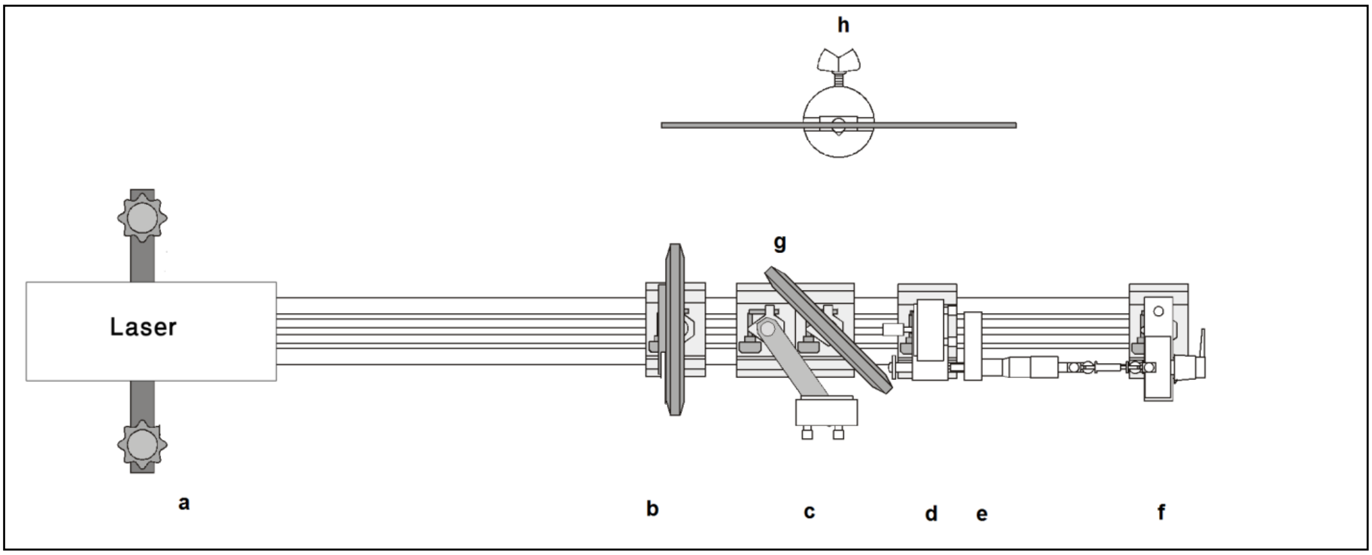


Illustration 2: Experiment Setup

Equipment

1 He-Ne Laser, linearly polarised 471 830
1 Lens in frame, f = 5 mm 460 01
1 Beam splitter 471 88
2 Planar mirror with fine adjustment...................... 473 461
1 Cantilever arm.. 460 380
1 Fine adjustment mechanism 473 48
1 Screen, translucent 441 53
1 Saddle base 300 11
1 Optical bench, standard cross section, 1 m 460 32
1 Optics rider 60/50... 460 373
5 Optics rider 90/50... 460 374

Safety note

The He-Ne laser complies with DIN EN 60825: Laser equipment safety.

Observing the corresponding notes in the operating manual makes the experimentation with the He-Ne laser safe.

- Do not look into the direct or reflected laser beam.
- Avoid crossing the glare threshold (so no observer gets blinded).

Remarks
Optical components with damaged or dirty surfaces can cause disturbances in the interference pattern.
Handle plane mirrors, beam splitters and spherical lenses carefully, keep them dust-free and do not touch them with bare hands.

Setup

Illustrations 1 and 2 represent the arrangement of the Michelson interferometer on the optical bench. The assembly requires the following steps. The cm graduations are on the left side of the optics rider.

Assembly on the optical bench:

- Attach the He-Ne laser (a) in the optics rider 60/50 to the left end of the optical bench.
- Attach the reduction gear unit of the fine adjustment mechanism (f) with the magnetic bench on the gear surface, and attach the optical bench to the other end (approx. 77 cm).
- Clamp the plane mirror (d) on top of the fine adjustment mechanism, and install the reduction gear unit (f) on the bench (61 cm).
- Set the micrometer screw of the fine adjustment mechanism (e) to 10 mm, so the mirror can move in both directions.
- Carefully connect the reduction gear unit and the fine adjustment mechanism to the cardan shaft.
- If necessary, shift the optics rider of the fine adjustment mechanism (e) and set the surface height of the reduction gear unit (f) so the cardan shaft is as straight as possible and neither completely stretched nor compressed. Otherwise, shifting the fine adjustment mechanism can then corrupt the measurement.

Remark: In the following steps, turn on the laser only briefly to adjust each optical component, and turn it back off before adding the following component to prevent the appearance of unintentional reflexions.

- Set the laser's height so the beam is centered on the plane mirror (d).
- Orient the plane mirror (d) by adjusting the set screws on the rear so the reflected laser beam reflects back to itself.
- From now on, do not adjust the set screws on the plane mirror (d) anymore!

- Install the beam splitter (g) on the optical bench (50 cm) in front of the plane mirror (d):

  Orient the beam splitter (g) to 45° so the two reflected laser beams travel perpendicularly to the optical bench.

  Attach the translucent screen (h) in the saddle base, and install it perpendicularly to the beam splitter so the laser beam is centered on it.
- Install the plane mirror (c) on the optical bench (45 cm) using the cantilever arm in front of the beam splitter (g):

  Orient the plane mirror (c) so the laser beam is centered on it and reflected through the beam splitter onto the translucent screen.

  Orient the plane mirror (c) by adjusting the set screws on the rear so the reflected laser beam reaches the exact same point as the first laser beam.
- Install the lens (b) on the optical bench (40 cm) in front of the optics rider of the plane mirror (c):

  Set the height of the lens so the direct laser beam is as close to its center as possible. A large spot of light should now appear on the translucent screen. If necessary, slightly turn the laser in the optics rider.

After a short time (1 to 2 seconds) without any jolt to the construction, a concentric ring system should appear in the spot of light. If necessary, adjust the set screws on the plane mirror (c) to make them very visible in the middle of the spot of light.

Remark: The interference pattern is considerably brighter and therefore easier to observe if the laser is switched to an output of 1 mW. Since the beam's path can thus be slightly changed, the spherical lens's position or the beam's course must be readjusted if necessary.

Fine tuning:

In case you still cannot detect a striped pattern on the translucent screen:

- Slightly change the beam's path by adjusting the beam splitter (g) and the mirror (c), and if necessary readjust the spherical lens.

The better the two beamlets' parallelism between the beam splitter and the screen, the greater the interference fringe's width and distance:

- Set the interference pattern to a format that is comfortable to observe by making small changes to the mirror's orientation.

Procedure

- Avoid mechanical jolts to the optical bench (e.g. do not wiggle the desk).
- Avoid the formation of streaks of air in the construction, e.g. from breathing or drafts.
- Mark a spot on the translucent screen (h) where you can count the interference fringes passing by.
- Slowly and evenly adjust the gear knob (it may take several revolutions) by lightly applying your finger to the lever of the reduction gear unit (f), until the interference fringes start moving.
  Then complete at least one more revolution with the gear knob.
  This eliminates the gear's backlash.
- Keep turning the gear knob in the same direction, and simultaneously count the interference fringes that cross the mark and the revolutions of the reduction gear unit.

Remark: If the plane mirror, and therefore the interference pattern, has a jerking motion, lubricate the fine adjustment mechanism's sliding bush.

Measurement Example

Table 1: Number Z of the intensity maxima counted compared to the number N of revolutions of the reduction gear unit

N	Z
1	16 ± 1
2	32 ± 1

Analysis and Result

The number N of revolutions of the reduction gear unit, the total displacement Δs of the plane mirror, the wavelength λ of the laser's light and the number Z of the counted intensity maxima have the following relation:

$$Z \cdot \lambda = 2\,\Delta s$$

where $\Delta s = N \cdot 5\ \mu\text{m}$

The factor 2 shows up in this equation, since the geometrical path is changed by Δs both for the arriving beam and for the reflected beam.

So λ has the conditional equation

$$\lambda = 2 \cdot \frac{\Delta s}{Z}$$

Table 2: Displacement Δs of the plane mirror and calculated wavelength λ

$\frac{\Delta s}{\mu\text{m}}$	$\frac{\lambda\text{nm}}{}$
5	625 (+ 42 / - 37)
10	625 (+ 20 / - 19)

Literature value for the red He-Ne line: λ = 632.8 nm.

The measuring accuracy for λ increases with the total displacement Δs.