EP13 Michelson interferometer

The Michelson interferometer is a well-known experimental equipment in the history of physics. Dr. Michelson-Morley proved that the ether does not exist by this equipment, thus providing an experimental basis for the basic hypothesis of special relativity. The Michelson interferometer can accurately measure the optical path difference in the interference of two beams of light, so it has a wide range of applications in the field of precision measurement. For example, the Laser Interferometer Gravitational Wave Observatory (LIGO) used to measure gravitational waves uses a Michelson interferometer to measure the optical path changes of lasers caused by gravitational waves.

Pre Lab Questions

1. How can we see the interference pattern?
2. If one reverses the handwheel during the measurement, what would happen? What should he do?

OBJECTIVE

1. To study the principle of Michelson interferometer
2. To learn how to measure laser wavelength using Michelson interferometer.

THEORY

1. Principle

The Michelson interferometer is a device that produces interference between two beams of light. A diagram of the apparatus is shown in Figure 1. The basic operation of the interferometer is as follows. Light from a light source is split into two parts. One part of the light travels a different path length than the other. After traversing these different path lengths, the two parts of the light are brought together to interfere with each other. The interference pattern can be seen on a screen.

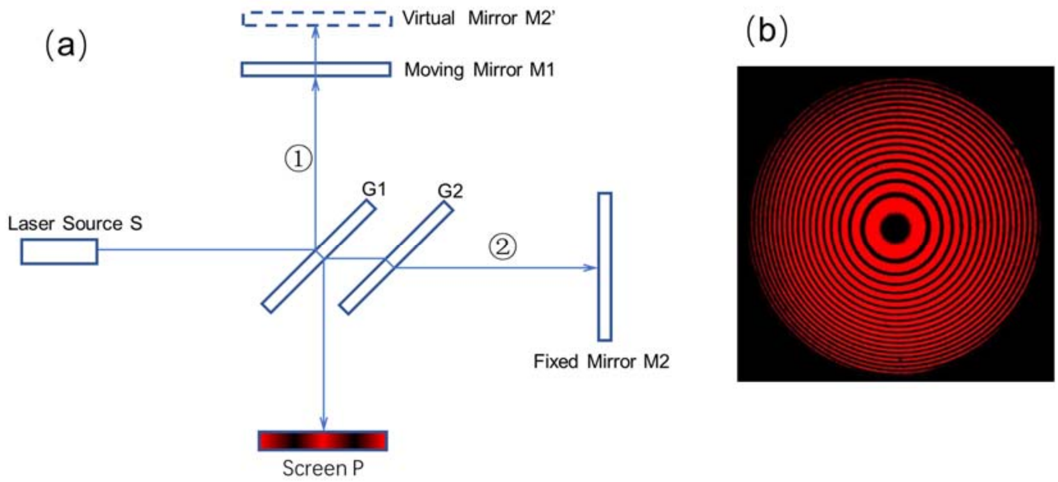

Figure 1: (a) Schematic diagram of the Michelson interferometer; (b) Circular fringe interference pattern

Figure 1(a) is a schematic diagram of the optical path of the Michelson interferometer. In the figure, M1 and M2 are two plane mirrors placed on two perpendicular paths where M2 is fixed. The position of M1 is controlled by a screw, which can move forward and backward. At the intersection of the two paths, there is a semi-reflective glass plate G1 at a 45° angle to the two axes. G1 is called a beam splitter that divides a beam of incident light into two beams with equal amplitude. G2 is a semi-reflective glass plate, placed in parallel with G1, and the thickness and refractive index are the same as G1. It compensates the optical path difference of light ① and ② due to the different times of passing through G1. It is also called compensation plate.

2. Interference fringes

The light emitted from the light source S is divided into two light at G1. The reflected light ① by G1 and travels toward M1, and the transmitted light ② travels toward M2 through G2. The two beams of light are reflected at M1 and M2 and return against their incident directions, and finally all reach screen P. Because the two beams of light are coherent light, the observer at P can see the interference fringes. When the observer looks from P to G1, in addition to directly seeing M1, he can also see the virtual image of M2′ of M2 in G1. The interference in the Michelson interferometer is the same as the interference produced by an air film with a thickness of d, where d is the distance between the virtual images of M1 and M2'.

3. Equal inclination interference fringes.

When M1 and M2' are parallel, (that is M1 and M2 are strictly perpendicular to each other), an annular equal-inclination interference fringe (Figure 1(b)) will be observed at the frosted glass screen at P. The optical path difference between the two beams of light reflected by M2 and M1 to P can be viewed as parallel light interference in between:

$$(2l_1 - 2l_2)cos\theta = 2\Delta d cos\theta = m\lambda$$

When m=k_i (k_i is an integer and i is the interference order), a bright ring appears, and when m=(2k+1)/2, a dark ring appears.

If we consider the very center of the field of view, that is θ=0, a bright spot can be observed when

$$2\Delta d = m\lambda$$

When Δd increases, more bright rings emerge from the center and the interference fringes will expand, and vise verse. When there are N rings emerged or submerged from the center, then

$$2\Delta d = N\lambda$$

in which, the wavelength of the light can be calculated:

$$\lambda = \frac{2\Delta d}{N} \qquad (1)$$

Experiment set-up

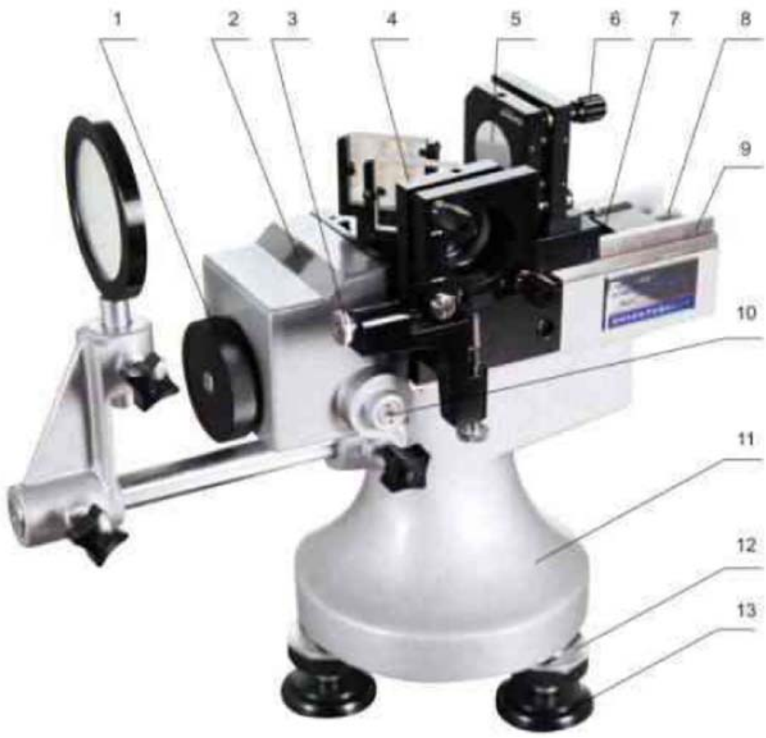

Figure 2 Image of Michelson interferometer

1.Coarse adjustment handwheel; 2. Reading window 3.6. Fine adjustment screw, 4. Fixed Mirror M2, 5. Moving mirror M5, 6. Precision screw. 9. Guide, 10 Fine adjustment handwheel; 11. Base, 12.Lock washer, 13 Leveling screw,

PROCEDURE

1. Observation of circular fringe interference pattern

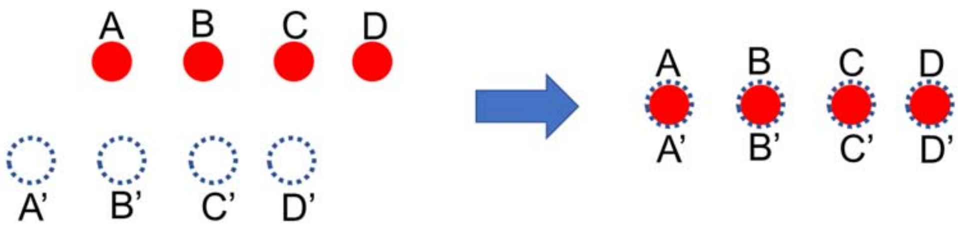

Figure 3 Adjustment of light spots

Switch on the laser source, let the laser perpendicularly irradiates the M2. Put the frosted glass plate between S and G1. Then look through G1 from position P. If the set-up is not calibrated, there are two lines of light spots with four spots in each line (Figure 3). First, rotate the coarse adjustment handwheel to position the M1 at 53-54 cm in the main rule. Second, find tune the fine adjustment screw on M2 to make the two lines of light spots overlap with each other. This guarantees that M1 and M2 are strictly perpendicular. Put the frosted glass plate at the view direction, and an interference pattern should appear on the glass (Figure 1(b)). Fine tune screw 3 or M2 to locate the circular fringe interference pattern at the center of the glass, and fine tune the handwheel 1 to make it large enough for easy observation.

2. Calibration of the reading system

The reading system of M1 is composed of the main ruler and micrometers at handwheel 1 and 10. The main ruler on the side of the guide rail is a scale with an accuracy of 1 mm. The relationship among the three is: the micro handwheel rotates for one cycle (100 scales) will leads to the movement of one scale in the reading window of the coarse handwheel; the coarse handwheel rotates one circle (100 scales) will lead movement of 1 mm on the main ruler. Therefore, the accuracy of the system is 0.0001 mm and can be estimated to be 0.00001 mm.

To calibrate the system, first rotate the micro handwheel clockwise to locate the reading exactly at zero. Second, rotate the coarse handwheel clockwise to locate the reading at any graduated line exactly in the reading window. Third, rotate the micro handwheel clockwise and observe the interference pattern. If there is moving of interference ring immediately when the micro handwheel is rotated, the system is now ready for measurement. Otherwise, repeat the above steps until it meets the requirement. Be sure that in the following, all the handwheel should be rotate clockwise. If any of the handwheel is rotated anticlockwise in the following operation, the data will be wrong due to the gear backlash. The system should be recalibrated and all the data should be remeasured. (The handwheel can also be rotated anticlockwise in the calibration, but all the rotation in the calibration and measurement should be anticlockwise.)

3. Experimental data & processing

Rotate the handwheel to adjust the interference center to the brightest. Record the position of the mirror M1 at this time. Rotate the handwheel to let the brightest ring emerge or submerge, and record the position of M1 after every 50 rings. Record a total of 10 numbers.

Table 1 To measure the wavelength of He-Ne laser

Rings	0	50	100	150	200	250	300	350	400	450
d (mm)										
5×Δd	Δd_{250-0}		Δd_{300-50}		$\Delta d_{350-100}$		$\Delta d_{400-150}$		$\Delta d_{450-200}$	
$\overline{\Delta d}$										
λ										

Calculate the wavelength of the He-Ne laser by equation (1) using the successive difference method. Calculate the relative error using the standard value of 632.8 nm.

Post Lab Questions

1. Why there are two lines of spots when we look at through G1?
2. What is the difference between the phenomenon observed when M1 comes close or far away to the virtual mirror M2’.

Extended reading

LIGO - A Gravitational-Wave Interferometer:
https://www.ligo.caltech.edu/WA/page/ligo-gw-interferometer