Engineering Optics

Lecture 26

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by

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Interferometer

Interferometry is a technique in which waves are made to interfere to extract information.

Interferometers are devices that extract information from interference. They are widely used in science and industry for the measurement of

1. microscopic displacements,
2. refractive index changes and surface irregularities.
3. In analytical science, interferometers are used to measure lengths and the shape of optical components with nanometer precision; they are the highest precision length measuring instruments in existence.
4. In Fourier transform spectroscopy they are used to analyze light containing features of absorption or emission associated with a substance or mixture.
5. An astronomical interferometer consists of two or more separate telescopes that combine their signals, offering a resolution equivalent to that of a telescope of diameter equal to the largest separation between its individual elements.

Michelson interferometer → most common design for optical **interferometry** and the first **interferometer** invented, by Albert Abraham **Michelson** in the late 19th century.

Michelson interferometer, Michelson-Morley Experiment

In the 19th century, physicists generally believed that just as water waves must have a medium to move across (water), and audible sound waves require a medium to move through (air), so also light waves require a medium, which was called the "**luminiferous" (i.e. light-bearing) "ether**".

The Michelson-Morley experiment became what might be regarded as the **most famous failed experiment** to date and is generally considered to be the **first strong evidence against the existence of the luminiferous ether.** Michelson was awarded the Nobel Prize in 1907, becoming the first American to win the Nobel Prize in Physics.

Physicists had calculated that, as the Earth moved in its orbit around the sun, the flow of the ether across the Earth's surface could produce a detectable "ether wind".

The idea of the experiment was to measure the speed of light in different directions in order to measure the speed of the ether relative to Earth, thus establishing its existence.

Taken from APS

Michelson-Morley Experiment

To measure the velocity of the Earth through the ether by measuring how the light changed, Albert Michelson (1852-1931) designed a device known now as an *interferometer*.

It sent the beam from a single source of light through a half-silvered mirror that was used to split it into two beams traveling at right angles to one another → series of reflections and transmissions → Any slight change in the amount of time the beams spent in transit would then be observed ***as a shift in the positions of the interference fringes***.

Michelson had done a preliminary version of the experiment in 1881. (at Case School of Applied Science in Cleveland, with Edward Morley, a professor of chemistry at neighboring Western Reserve College.)

The apparatus → allowed to be rotated slowly → As it rotated, according to the ether theory the speed of light in each of the two perpendicular arms would change→ shift in the interference pattern.

Results → a shift consistent with zero,

Repetition of the experiment → same results

What did we learn? → challenge the existence of the ether. (*what about sound?)*

Taken from APS

The Michelson interferometer

S → a light source (may be a sodium lamp)

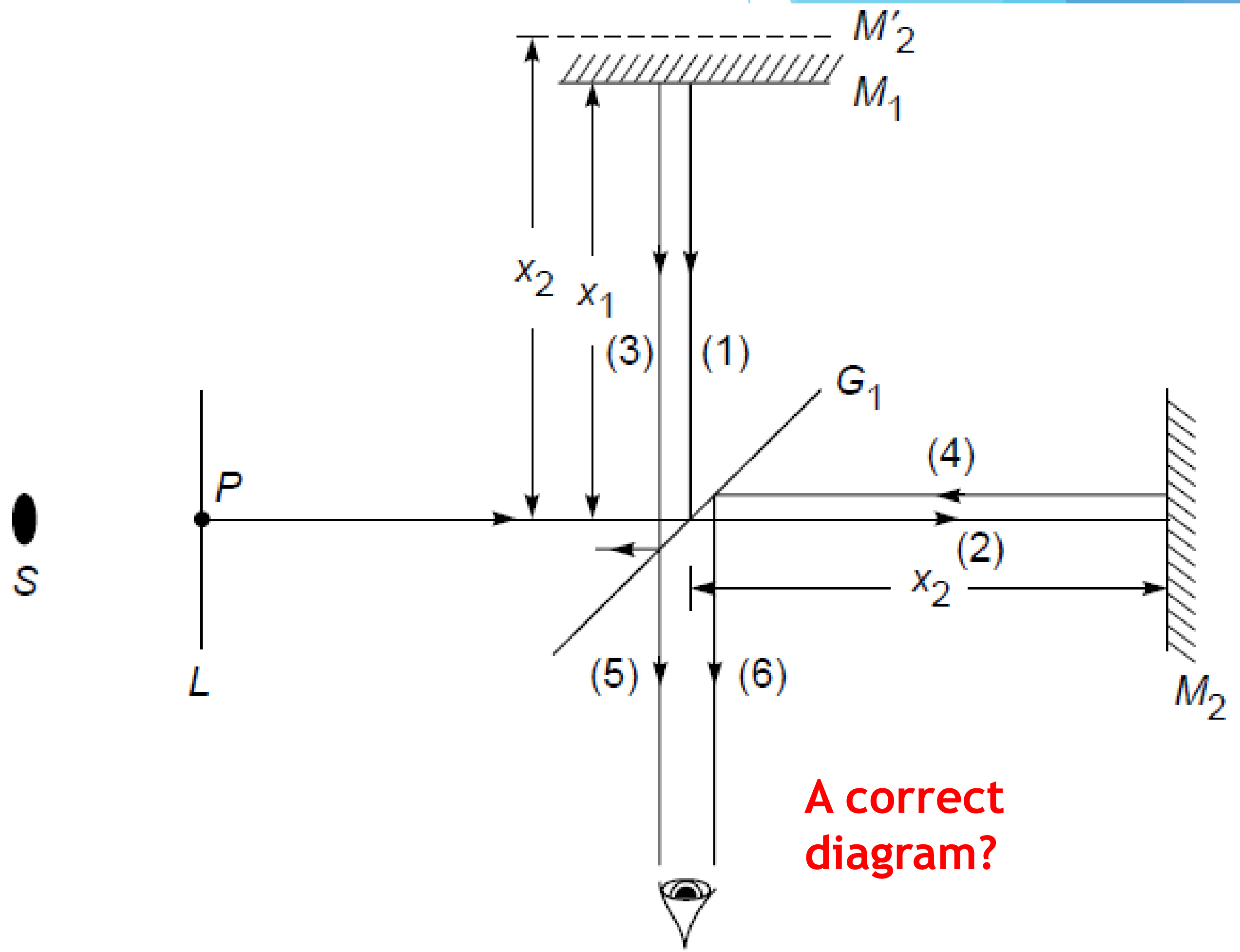
L → glass plate so that an extended source of almost uniform intensity is formed.

G_1 → a beam splitter
a beam incident on G1 gets partially
reflected and partially transmitted

M1 and M2 → good-quality plane mirrors
having very high reflectivity

One of the mirrors (M_2) is fixed and the other (usually M_1) is capable of moving away from or toward the glass plate G1 along an accurately machined track by means of a screw.

Usually mirrors M_1 and M_2 are perpendicular to each other and G_1 is at 45° to the mirror.



A correct diagram?

Schematic of the Michelson interferometer.

Optics, Ghatak

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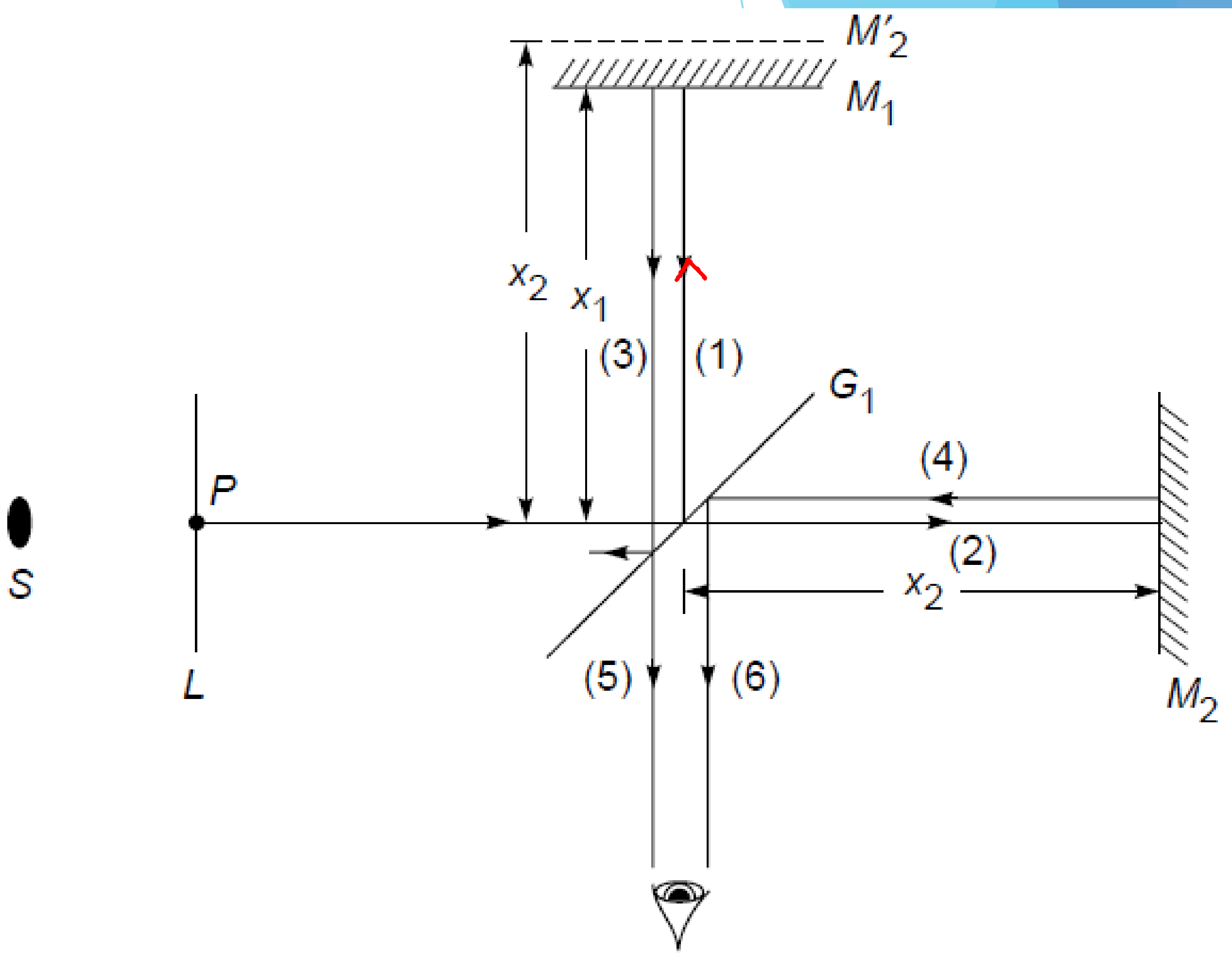

Schematic of the Michelson interferometer.

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The Michelson interferometer

Waves emanating from a point P get partially reflected and partially transmitted by the beam splitter G_1,

the two resulting beams are made to interfere

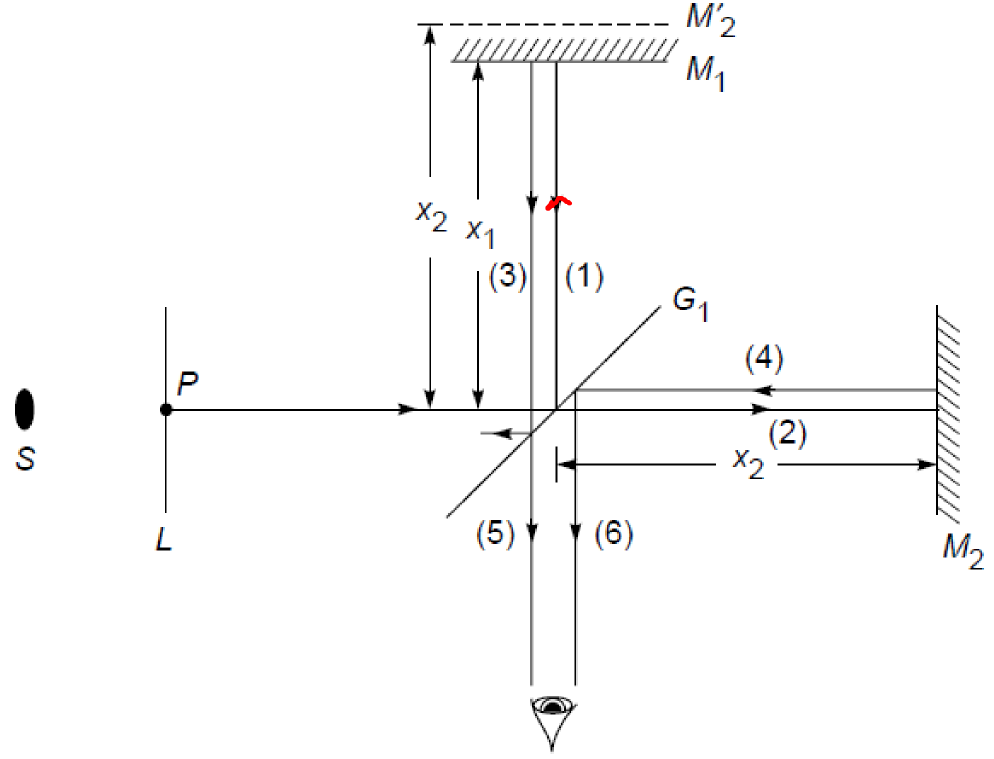
HOW??

1. The reflected wave (shown as 1 in Fig.) undergoes a further reflection at M_1, and this reflected wave gets (partially) transmitted through G_1; this is shown as 5 in the figure.

2. The transmitted wave (shown as 2 in Fig.) gets reflected by M_2 and gets (partially) reflected by G_1 and results in the wave shown as 6 in the figure.

1 & 2 ***interfere***

Same as interference with extended source on a film



Schematic of the Michelson interferometer.

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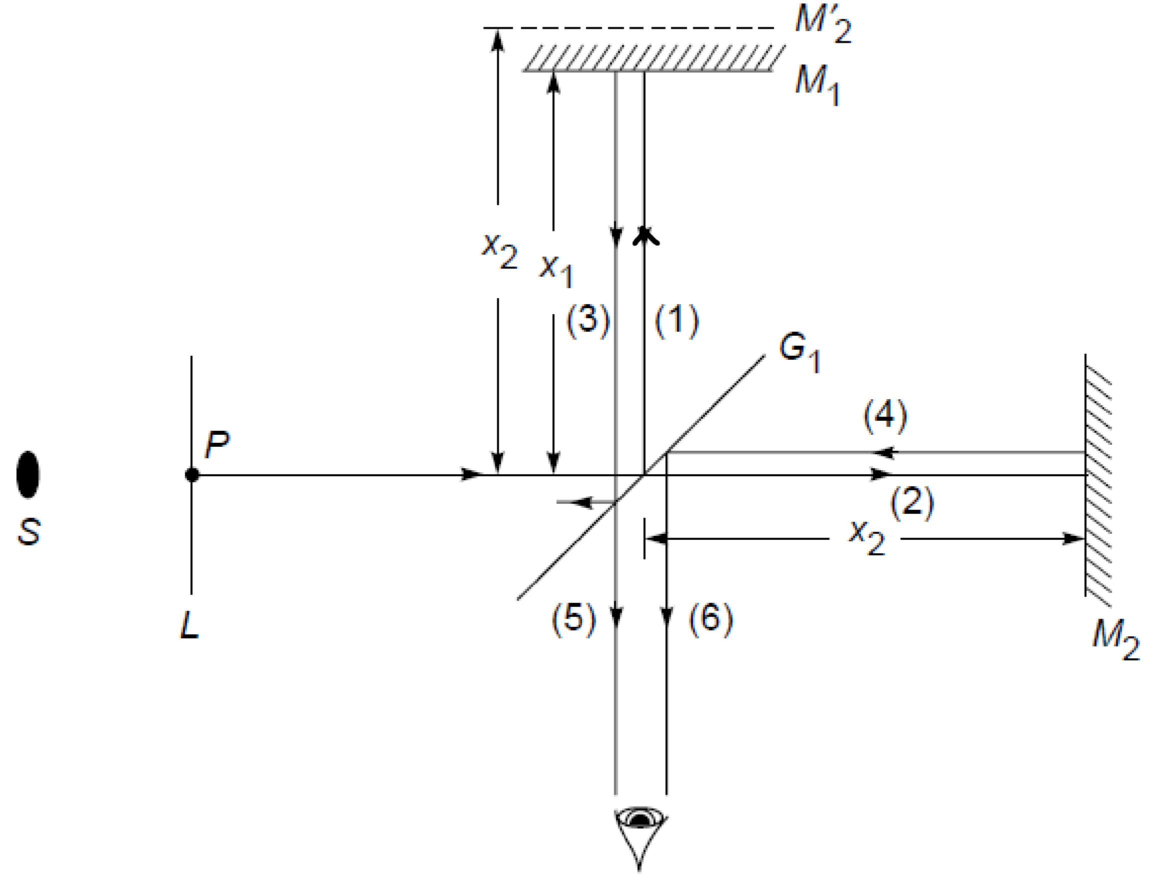
The Michelson interferometer

if x_1 and x_2 are the distances of mirrors M_1 and M_2 from the plate G_1, $d = x_1 \sim x_2$

To the eye the waves emanating from point P will appear to get reflected by two parallel mirrors (M_1 and M_2' — separated by a distance ($x_1 \sim x_2$).

if we use an extended source → if we have a camera, then on the focal plane we will obtain circular fringes, each circle corresponding to a definite value of θ



Schematic of the Michelson interferometer.

The Michelson interferometer

Now, if the beam splitter is just a simple glass plate, the beam reflected from mirror M_2 will undergo an abrupt phase change of π (when getting reflected by the beam splitter), and since the extra path that one of the beams will traverse will be $2(x_1 \sim x_2)$, the condition for destructive interference will be

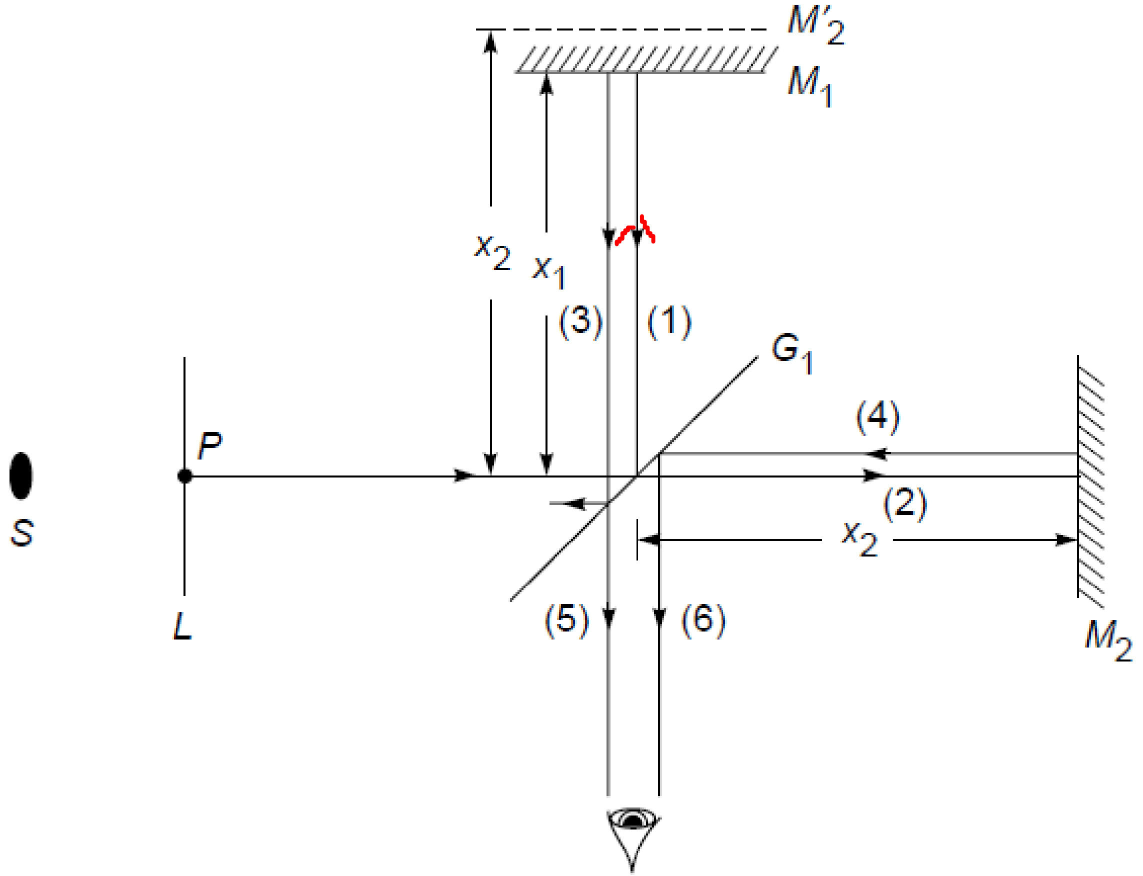
$$\boxed{2d \cos\theta = m\lambda}$$

where $m = 0, 1, 2, 3, \ldots$ and

$$d = x_1 \sim x_2$$

and the angle θ represents the angle that the rays make with the axis (which is normal to the mirrors as shown in Fig. 15.35). Similarly, the condition for a bright ring is

$$\boxed{2d \cos\theta = \left(m + \tfrac{1}{2}\right)\lambda}$$



Schematic of the Michelson interferometer.

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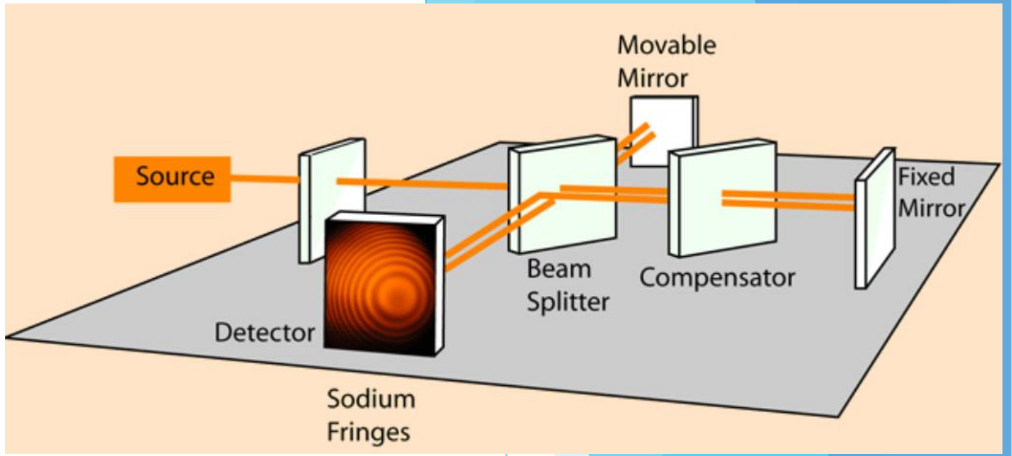
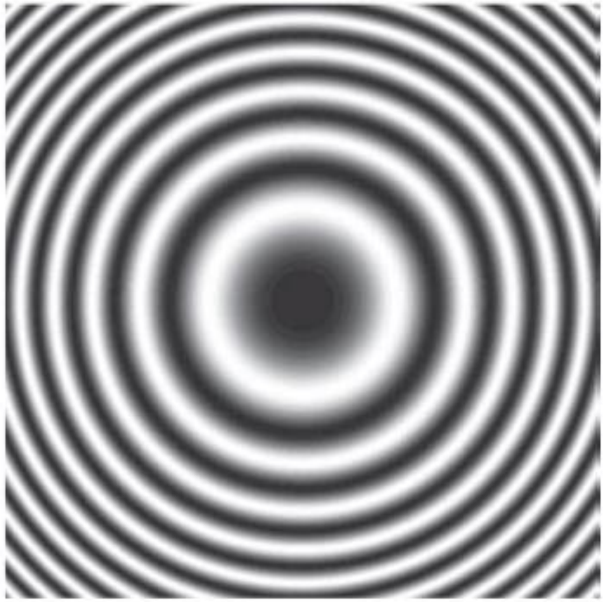
Problem -1



1. For example, for $\lambda = 6 \times 10^{-5}$ cm if $d = 0.3$ mm, the angles at which the dark rings will occur are



(a)

Problem -1

1. For example, for $\lambda = 6 \times 10^{-5}$ cm if $d = 0.3$ mm, the angles at which the dark rings will occur are

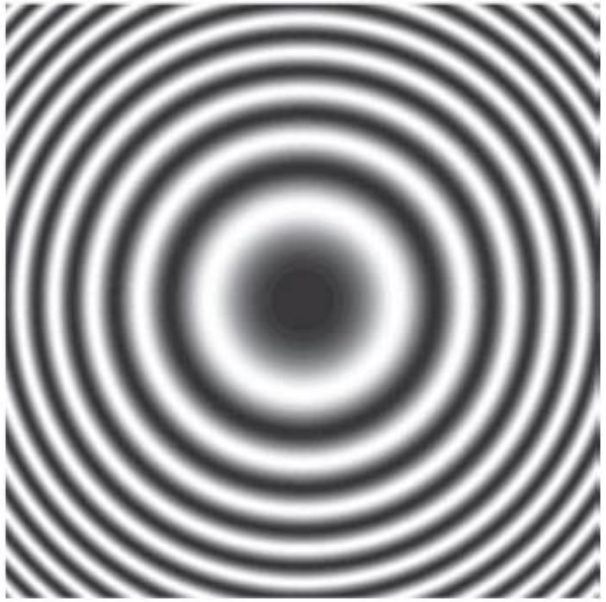
$$\theta = \cos^{-1} \frac{m}{500}$$

1000

Is it correct?

$$= 0°, 2.56°, 3.62°, 4.44°, 5.13°, 5.73°, 6.28°, \ldots$$

corresponding to $m = 1000, 999, 998, 997, 996, 995, \ldots$. Thus the central dark ring in Fig. 15.36(a) corresponds to $m = 1000$, the first dark ring corresponds to $m = 999$, etc.



(a)

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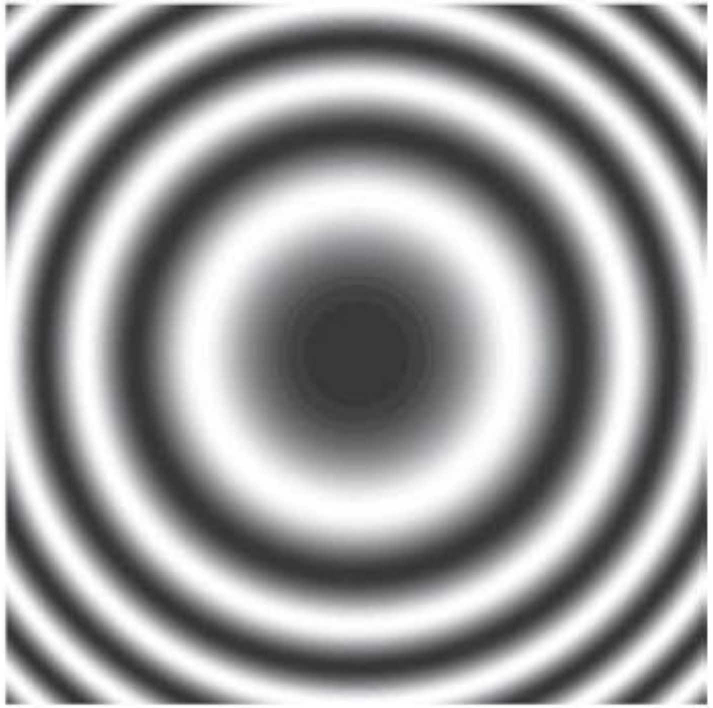
Problem -2

$d = 0.15$ mm, the angles at which the dark rings occur will be

$\lambda = 6 \times 10^{-5}$ cm

$d = 0.15$ mm



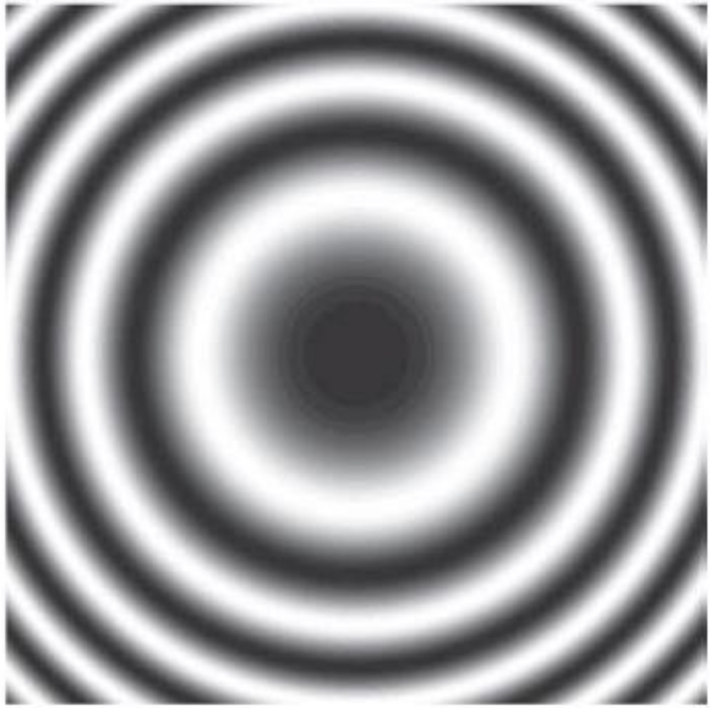
(b)

Problem -2

$d = 0.15$ mm, the angles at which the dark rings occur will be [see Fig.15.36(b)]

$$\theta = \cos^{-1}\frac{m}{500} = 0°, 3.62°, 5.13°, 6.28°, 7.25°, \ldots$$

where the angles now correspond to $m = 500, 499, 498, 497, 496, 495, \ldots.$



(b)

The Michelson interferometer

Thus as we start reducing the value of *d*, the fringes will tend to collapse at the center

Conversely, if d is increased, the fringe pattern will expand.

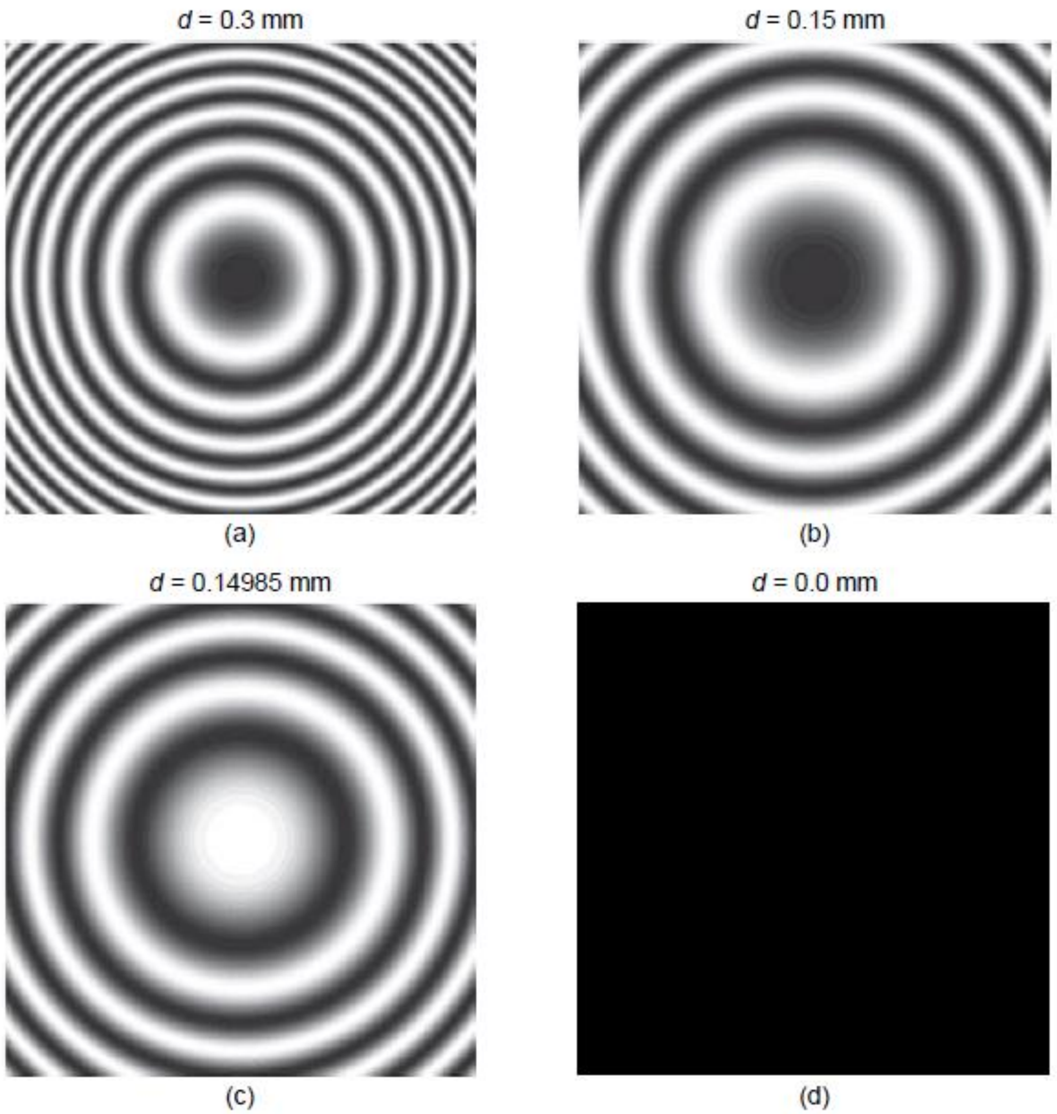
if N fringes collapse to the center as mirror M_1 moves by a distance d_0, then we must have

$$2d = m\lambda$$

$$2(d - d_0) = (m - N)\lambda$$

where we have set $\theta' = 0$ because we are looking at the central fringe. Thus

$$\lambda = \frac{2d_0}{N}$$



Computer-generated interference pattern produced by a Michelson interferometer.

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Wavelength measurement

This provides us with a method for the measurement of the wavelength. For example, in a typical experiment, if 1000 fringes collapse to the center as the mirror is moved through a distance of 2.90×10^{-2} cm, then

$$\lambda = 5800 \text{ Å}$$

The above method was used by Michelson for the standardization of the meter. He found that the red cadmium line ($\lambda = 6438.4696$ Å) is one of the ideal monochromatic sources, and as such this wavelength was used as a reference for the standardization of the meter.

Thank You