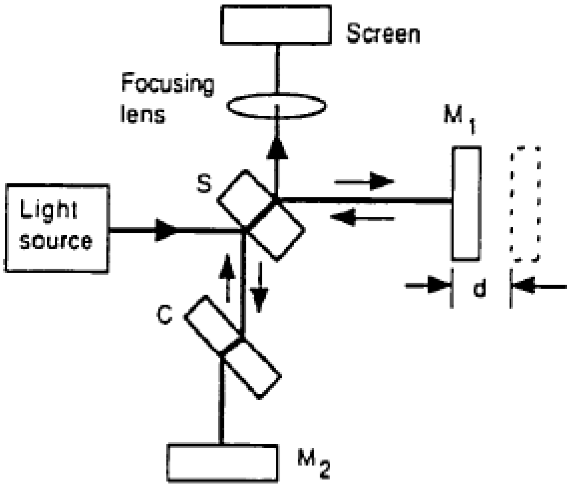
Answer on Question #60466-Physics-Optics

Discuss the principle of Michelson interferometer. How can it be used to determine the refractive index of a thin plate and wavelength of monochromatic light?

Answer

The Michelson interferometer is a historically important device which provides simple interferometric configuration for introducing basic principles. This device works under the principle of interference. Michelson Interferometers can be used to find out the refractive index of glass plates or thin films.

A diagram of the apparatus is shown in Fig. 1.



The Michelson interferometer operates on the principle of division of amplitude rather than on division of wavefront. Light from a light source strikes the beam splitter (designated by S) and is split into two parts. The beam splitter allows 50% of the radiation to be transmitted to the translatable mirror MI. The other 50% of the radiation is reflected back to the fixed mirror M2. Both these mirrors, MI and M2, are highly silvered on their front surfaces to avoid multiple internal reflections. The compensator plate C is introduced along this path to have the same optical path length when MI and M2 are of same distance from the beam splitter. After returning from MI, 50% of the light is reflected toward the frosted glass screen. Likewise, 50% of the light returning from M2 is transmitted to the glass screen. The two beams arc superposed and one can observe the interference fringe pattern on the screen. The character of the fringes is directly related to the different optical path lengths traveled by the two beams and, therefore, is related to whatever causes a difference in the optical path lengths.

In a Michelson interferometer, light is split into two beams by the beamsplitter (amplitude splitting), reflected by two mirrors, and passed again through the glass plate to produce interference phenomena behind it. A lens is inserted between the light beam and the beamsplitter so that the light source lies at the focal point, since only enlarged light spots can exhibit interference rings.

Consider a thin glass plate of thickness t and refractive index n, inserted normal to the path of one of the two interfering beams in Michelson interferometer. The optical path length of the beam through the plate is nt, while the optical path length through an equal thickness of air is just t, so the increase in optical path length caused by inserting the plate is $(n-1)t$. The beam traverses the plate twice, so the total path difference will be $2(n-1)t$. If N is the number of fringes displaced by inserting the plate, then

$N\lambda = 2(n-1)t.$

After adjusting the mirrors to obtain circular fringes with a single central dark spot, the plate is introduced into the path of one of the interfering beams and the fringes are displaced. M1 is moved a distance d closer, until a single central dark spot is again obtained. The distance d moved is noted and the number of fringes N that disappear is counted. Then, since the insertion of the glass plate increased the optical path length by $2(n-1)t$, and the mirror motion decreased it by $2d$, $2d$ must equal $2(n-1)t$, so the refractive index n of the plate can be calculated from $N\lambda = 2d = 2(n-1)t$.

With a laser, the light source is more precisely monochromatic, so the measurement of n can be more accurate. In the Michelson interferometer, if N fringes are displaced when the plate is rotated through an angle θ from its original orientation normal to the path, the refractive index of the plate is

$$n = \frac{(2t - N\lambda)(1 - Cos\,\theta) + \dfrac{N^2\lambda^2}{4t}}{2t(1 - Cos\,\theta) - N\lambda}$$

where t is the thickness of the plate and λ is the wavelength of the laser. The last term in the numerator is often neglected. However, this causes an error that increases with θ, reaching $\sim 1\%\ at\ \theta = 30°$, potentially destroying the increased accuracy gained by using a laser light source.

The above equation can be approximated to get

$$n = \frac{(2t - N\lambda)(1 - Cos\,\theta)}{2t(1 - Cos\,\theta) - N\lambda}$$