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Topic for

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MICHELSON INTERFEROMETER

Albert Abraham Michelson developed an instrument using the concept of interferometry, the so-called Michelson Interferometer, to verify the ether-hypothesis. Nowadays it is used to determine wavelength of light, refractive index of thin material etc.

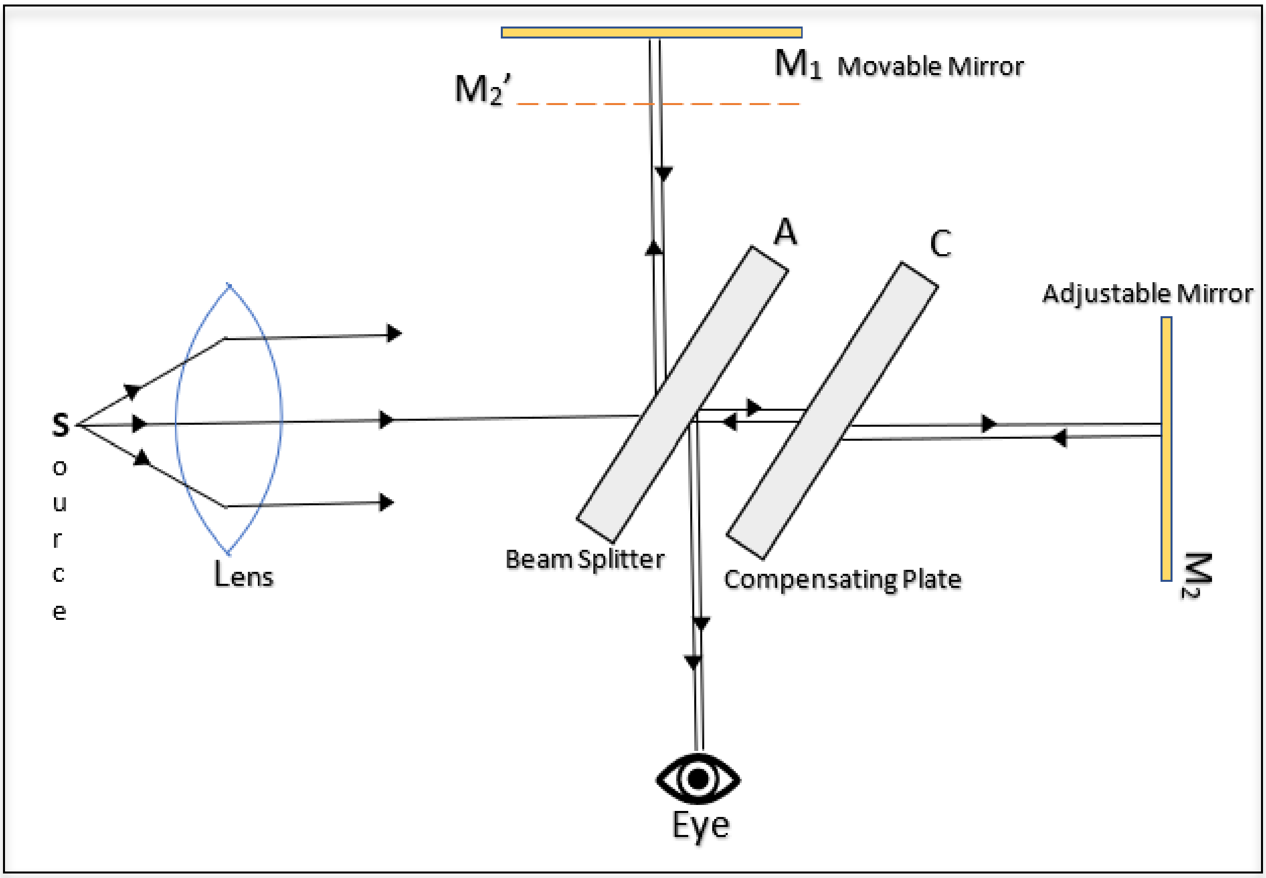


Fig 1. Schematic Diagram

Essential parts of Michelson Interferometer

Two optically plane mirrors **M_1** and **M_2** with highly silvered front surface. **M_2** is fixed and **M_1** is movable with the help of a calibrated screw. Both mirrors are also capable of slight rotation about their horizontal as well as vertical axis with the help of screws.

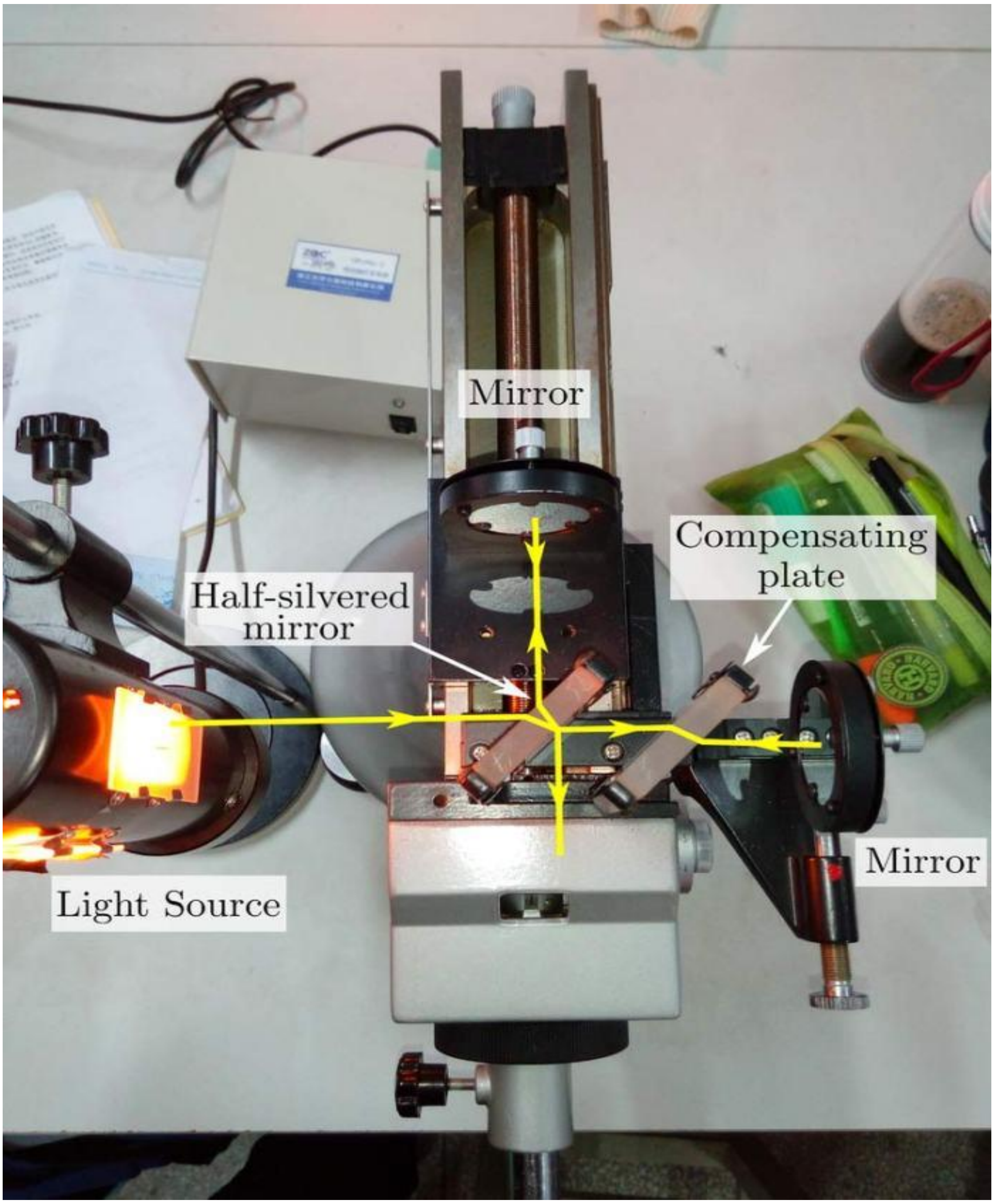


Fig 2. Laboratory Arrangement

Two plane parallel glass plates **A** and **C** having equal thickness. Rear side of **A** is half-silvered. **A** is called beam splitter and Cis called compensating plate.

An extended source **S** of monochromatic light and a lens **L**.

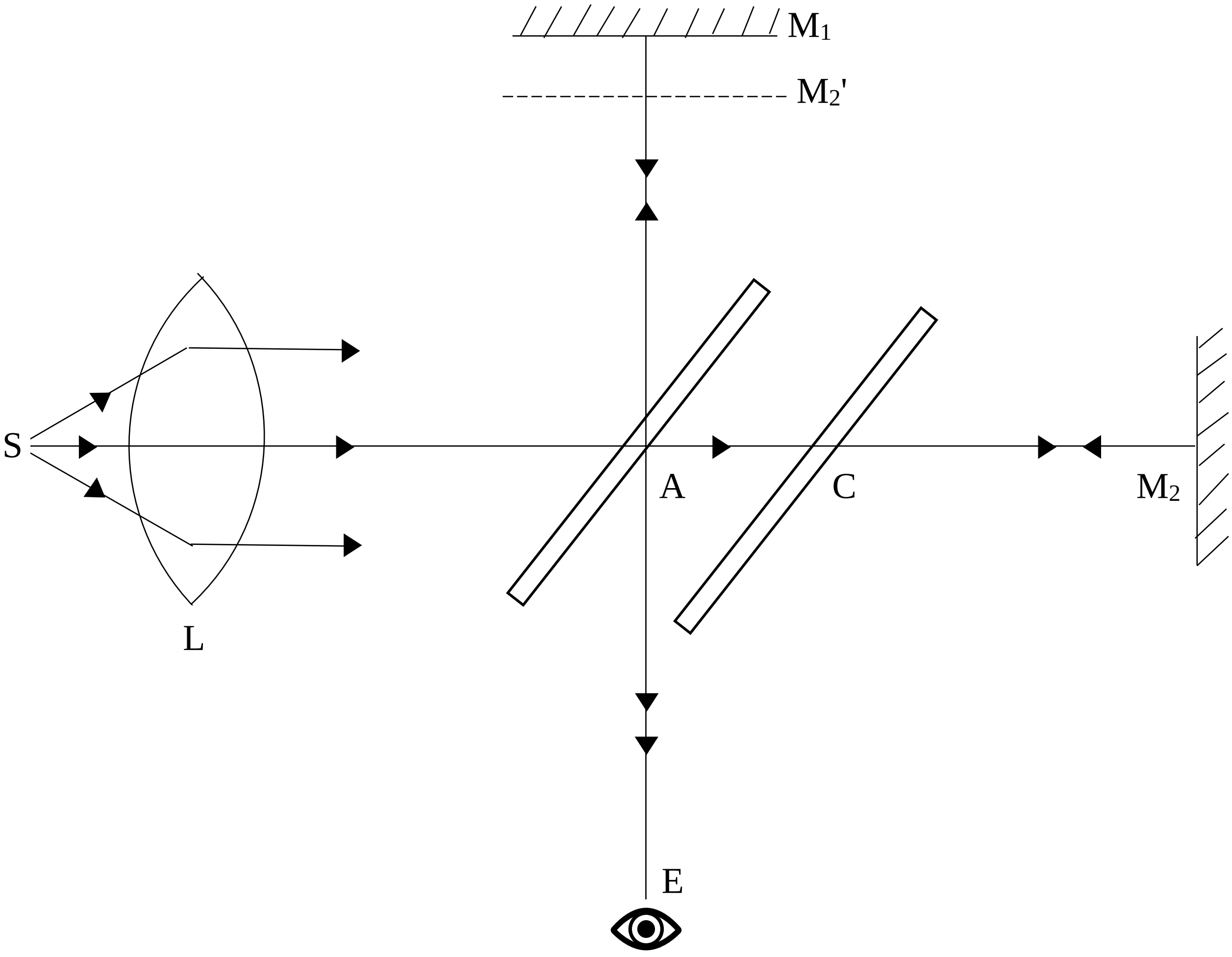
How does it work?

Monochromatic light from the extended source **S** is made parallel by the lens **L** and then is incident on the beam splitter **A**. Light is divided into two parts of nearly equal amplitudes by partial reflection and transmission at the rear side of **A**. (as the rear side of **A** is half-silvered)

The reflected wave proceeds to $\mathbf{M_1}$. Then it is reflected back by the mirror $\mathbf{M_1}$ towards the beam splitter **A**. Finally, a part of it transmits through **A** along AE.

The transmitted wave proceeds towards $\mathbf{M_2}$. Then it is reflected back by the mirror $\mathbf{M_2}$ towards the beam splitter **A**. Finally, a part of it is reflected at the rear side of **A** along AE.

So, we get two coherent waves along AE. These two waves produce interference fringes that can be observed by looking from E into the mirror **M_1**.



Why the compensating plate C is needed?

It is evident from the above picture that the wave reflected from **M_1** crosses the glass plate **A** thrice, whereas the wave reflected from **M_2** traverses the plate **A** only once. To compensate for this extra path in glass an exactly similar glass plate is placed on the path of the wave reflected from **M_2**.

*If we use a monochromatic light for production of fringes, then use of this compensating plate **C** is not essential. We just need to consider the additional difference in optical path of interfering waves.

** If we use a white light for production of fringes, then use of this compensating plate **C** is absolutely necessary for producing achromatic fringes. Additional difference in optical path will vary with wavelength. So, the additional difference in optical path must be eliminated for production of achromatic fringes.

Is there any additional phase change due to reflection?

Both the rays proceeding towards mirror $\mathbf{M_1}$ and $\mathbf{M_2}$ suffer identical phase change due to reflection from optically rarer to optically denser medium. Also, the phase change suffered by the ray proceeding towards mirror $\mathbf{M_1}$ due to reflection at the rear side of **A** and the phase change suffered by the ray coming from mirror $\mathbf{M_2}$ due to reflection at the rear side of **A,** are same. In both cases reflections are taking place from optically rarer to optically denser medium (glass to silver and air to silver).

Hence, the optical path difference between the interfering waves is the difference in path travelled in air.

Formation of fringes

On looking along EA we can see the mirror $\mathbf{M_1}$ together with the image $\mathbf{M_2'}$ of the mirror $\mathbf{M_2}$. This image $\mathbf{M_2'}$ is formed by reflection from the half-silvered surface of **A**.

So, we can consider that one of the interfering rays comes by reflection from $\mathbf{M_1}$ and other appears to come by reflection from $\mathbf{M_2'}$.

Depending upon the distance between $\mathbf{M_1}$ and $\mathbf{M_2'}$ and the angle between them we may get fringes of different shapes.

We will now discuss the formation of circular and straight fringes.

Formation Of Circular Fringes

Necessary adjustment for producing circular fringes ---

(i) Two mirrors $\mathbf{M_1}$ and $\mathbf{M_2}$ need to be perfectly vertical and at right angles to each other.

(ii) Half-silvered surface of A should be at angle of 45° with the incident ray.

This adjustment makes the image $\mathbf{M_2'}$ of the mirror $\mathbf{M_2}$ exactly parallel to $\mathbf{M_1}$

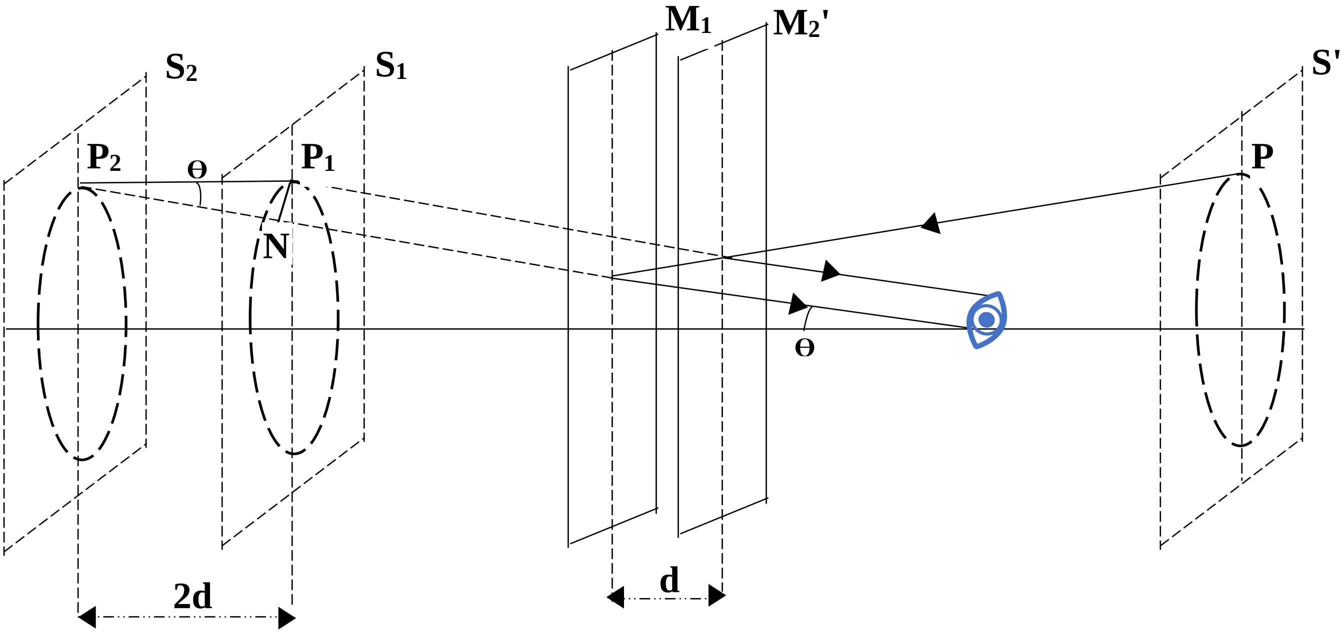
Let us now try to understand the formation of circular fringes. See the image below.

The real extended source **S** has been replaced by its image **S'** formed by reflection at **A**.

S_1 and **S_2** are the images formed by the reflection from **M_2'**and **M_1**. These images are working as virtual sources for production of fringes.

These two virtual sources are coherent and as a result each pair of corresponding points are in exactly same phase at all instants.

Consider a point **P** of the source **S**. **P_1** and **P_2** are the two virtual images of the point **P** formed by the reflection from **M_2'**and **M_1** respectively. Hence **P_1** and **P_2** are the corresponding points of the virtual sources **S_1** and **S_2** respectively.



Let **d** is the distance between **M_1** and **M_2'**. Hence, the distance between the virtual sources **S_1** and **S_2** is 2**d**.

Let **ϴ** is the inclination of the reflected rays with the normal to surface of **M_1** and **M_2'**.

Hence, the path difference between the two rays coming to the eye, from the corresponding points **P_1** and **P_2** is 2**d** cos**ϴ**.

[$P_2N / P_1P_2 = \cos\Theta$; $\therefore$ $P_2N = P_1P_2 \cos\Theta$, Now, $P_1P_2 = 2d$; $\therefore$ $P_2N = 2d \cos\Theta$]

The intensity will be maximum when $2\mathbf{d}\cos\boldsymbol{\Theta} = \mathbf{m}\,\boldsymbol{\lambda}$
and intensity will be minimum when $2\mathbf{d}\cos\boldsymbol{\Theta} = \mathbf{(2m+1)}\,\boldsymbol{\lambda}\mathbf{/2}$

Where, λ is the wavelength of light and

$m=0,1,2,3, \ldots\ldots\ldots..$

d and λ are constants. So, for a given order number **m**, $\boldsymbol{\Theta}$ will be constant.

Hence, the maxima will be in the form of a concentric circles about the foot of the perpendicular from the eye to the mirrors.

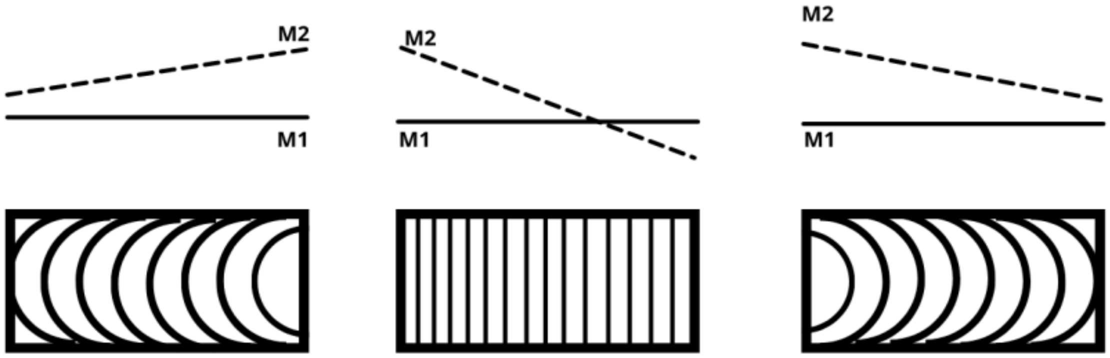
These fringes are called *fringes of equal inclination*.

These fringes are situated at infinity. Hence, they are *non-localized*.

Formation Of Straight Fringes

When mirrors **M_1** and **M_2'** are not exactly parallel, a wedge-shaped film is formed between them. The path of two reflected rays, originating from the same incident ray by reflection from **M_1** and **M_2'** are no longer parallel.

They intersect near **M_1** and hence the fringes are formed near **M_1**. The fringes are called localized fringes and to see them the eye must be focused on the vicinity of **M_1**.



These fringes are curved with their convex side toward the thin edge of the wedge as shown in the figure. The thin edge of the wedge is to the left and therefore the fringes are convex toward the left.

As we go on decreasing the separation between **M_1** and **M_2'**, the fringes move across the field of view away from the thin edge of the wedge and at the same time gradually become straight. When **M_1** and **M_2'** intersect, the lines are perfectly straight as shown in the figure.

We have two wedges opposing each other. So, the line should appear curved on both sides of the intersection. But for a small field of view, they appear straight.

When **M$_1$** is again moved such that the mirror **M$_1$** and the virtual image **M$_2$'** of mirror **M$_2$** get a position as shown in the figure. The fringes are again curved but with their convex side towards the right. Localized fringes become invisible for large path differences of the order of several millimetres.

White Light Fringes

Instead of monochromatic light if we use white light, its constituent wavelength gives rise to its own set of fringes of different widths. For zeroth order fringe the path difference is zero for all wavelengths. Hence, the central fringes or zeroth order fringes corresponding to each wavelength will coincide and it will be dark.

When the path difference between the interfering rays is considerable, then constituent wavelengths give rise to their own set of fringes of same order at slightly different location.

So, the central fringe is surrounded by a few coloured fringes.

After that there is so much overlapping of fringes of different wavelengths, we get general illumination.

The importance of these white light fringes is that the position of central fringe can be located very easily as it is dark.