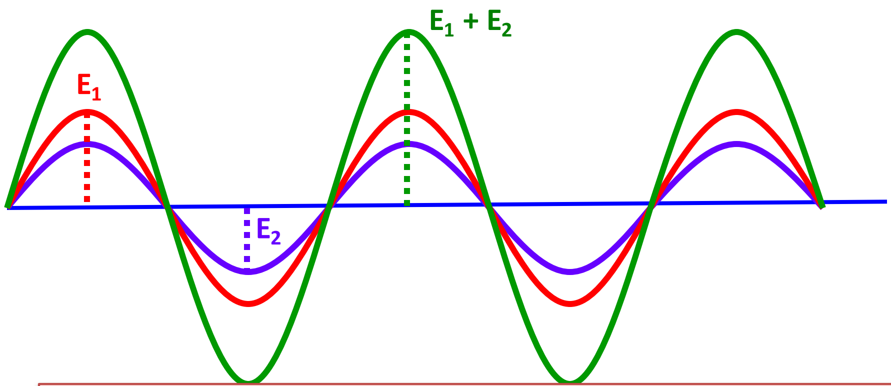
Thin film interference

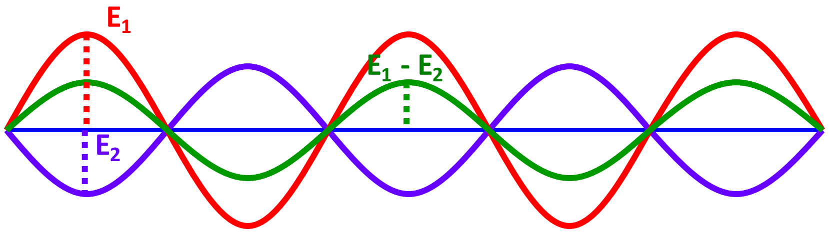
Interference

The phenomenon of modification in intensity of light due to mixing/superimposing of two or more light waves is called **Interference of Light.**

Constructive and Destructive Interference



Constructive Interference $E = E_1 + E_2$



Destructive Interference $E = E_1 - E_2$

1st Wave (E_1)

2nd Wave (E_2)

Resultant Wave

Reference Line

Phase difference (Φ) = ($2\pi/\lambda$) path difference

Condition for Constructive Interference :

Phase difference $\Phi = 2n\pi$

Path difference $= n\lambda$

where n = 0, 1, 2, 3, …….

Condition for Destructive Interference :

Phase difference $\Phi = (2n \pm 1)\pi$

Path difference $= (2n \pm 1)\lambda/2$

where n = 0, 1, 2, 3, ……. for +ve

where n = 1, 2, 3, ……. for - ve

Conditions for sustained interference

1.The two sources must be coherent.

2. The sources must be monochromatic.

3. The interfering waves should have same amplitude or intensity

4. The distance between two sources should be small.

5. The perpendicular distance of screen from two sources should be large.

6. Sources must be narrow.

7. The two interfering waves must have the same plane of polarization.

Methods for obtaining Coherent Sources

Division of Wavefront

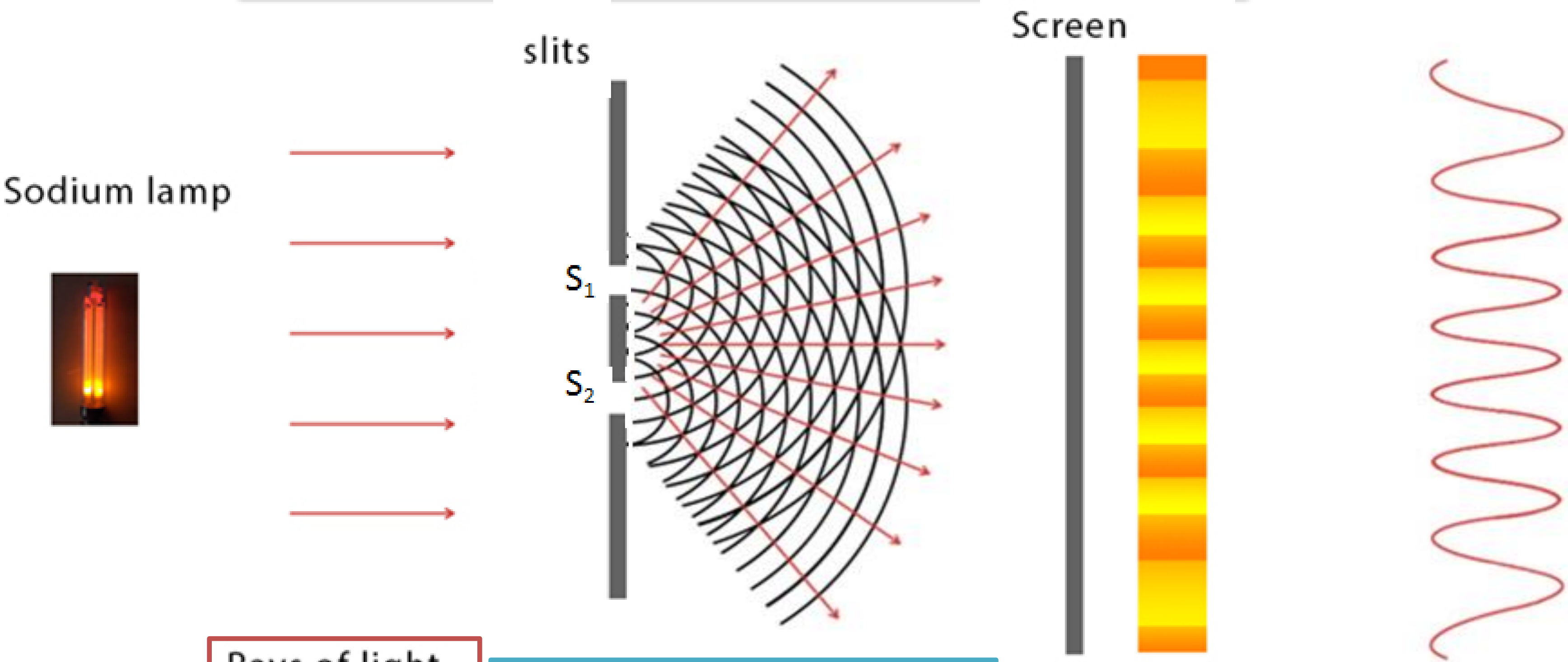
Examples: Young's double slit, Biprism etc

Division of Amplitude

Examples: Thin film, Newton's Ring etc

Division of Wavefront

Double-Slit Experiment



Light source

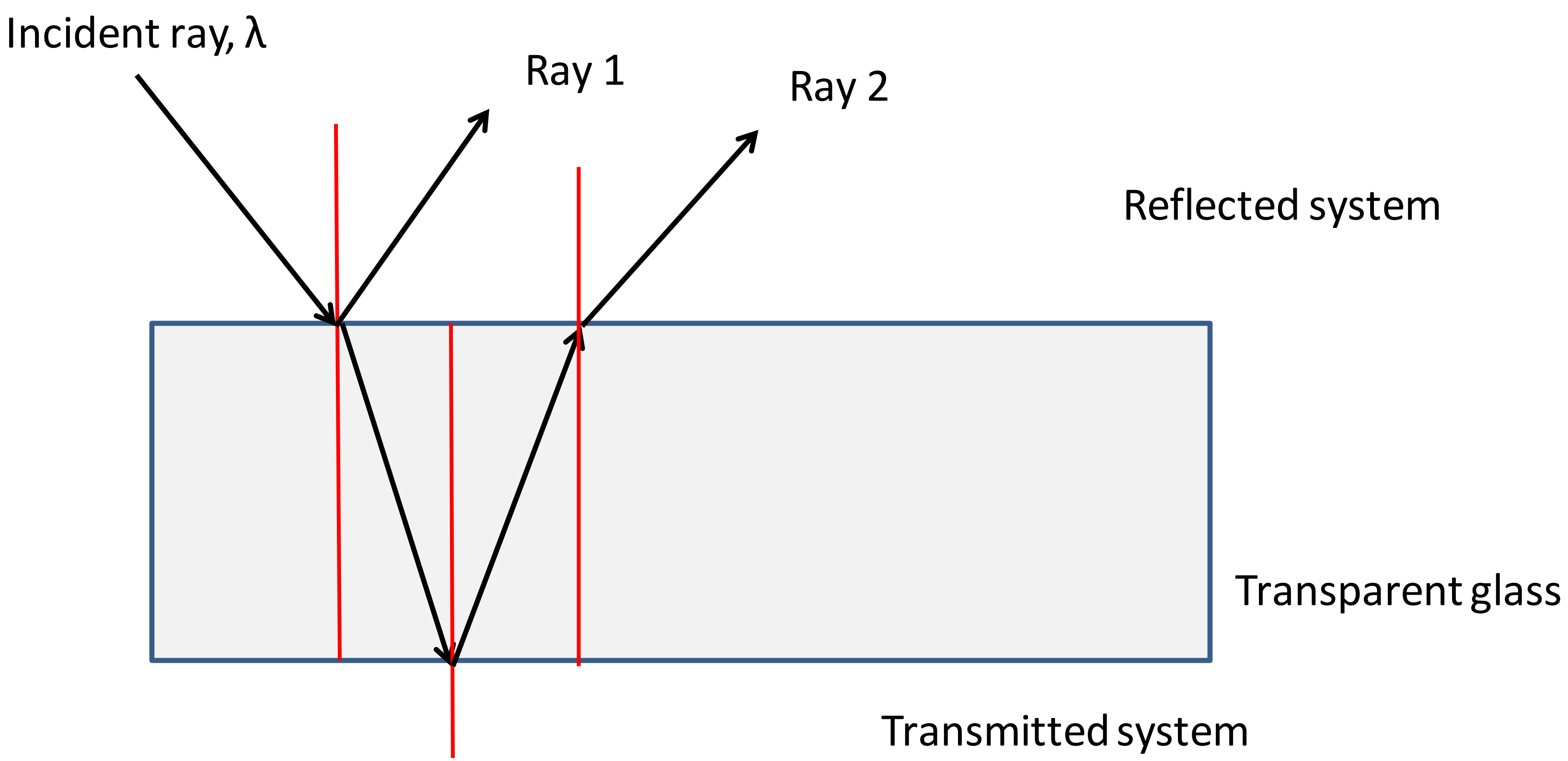
Rays of light coming from the source reach the slits

Interference of light waves due to two tiny slits and arrows indicate direction of wave propagation

Alternating bright and dark fringes due to interference of light waves

Intensity of the fringes shows the maxima and minima

Division of Amplitude



Let’s discuss about reflected rays 1 and 2

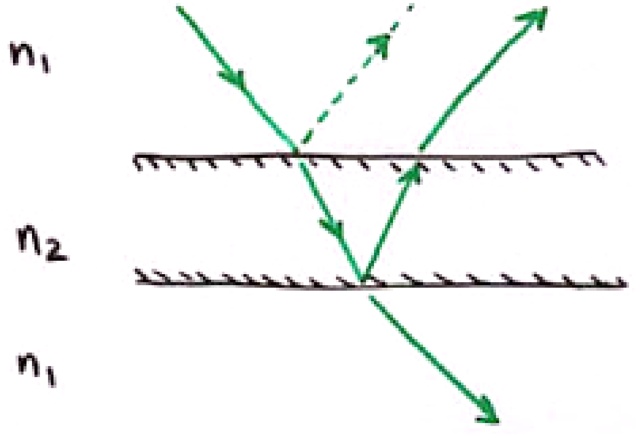
Hence they will interfere Reflected system

In this, intensity or amplitude of waves changes.

Hence it is called Interference due to Division of Amplitude

Thin Film

- **When a film of oil spread over surface of water is illuminated by white light , beautiful colours are seen.**
- **This is due to interference between the light waves reflected from the film and the light waves transmitted through the film.**
- **Thin film may be a thin sheet of transparent material such as glass, mica or an oil film enclosed between two transparent sheets or a soap bubble.**



1. Parallel Rays interference with each other?

2. How many rays will interfere ?

3. What about thickness?

Important Note

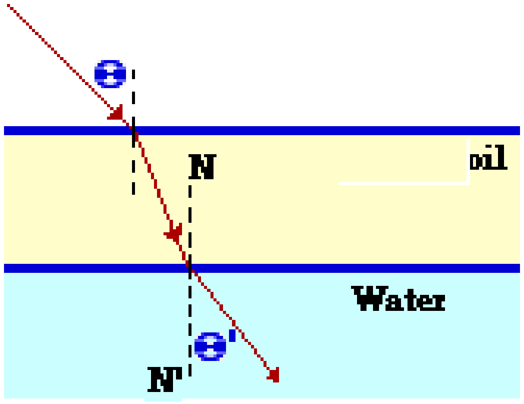
1. Thin film:

In optics, a transparent medium having thickness (0.1 λ) to (10 λ) is called thin film.

Example: layer of oil on glass or water surface

2. Optical Path:

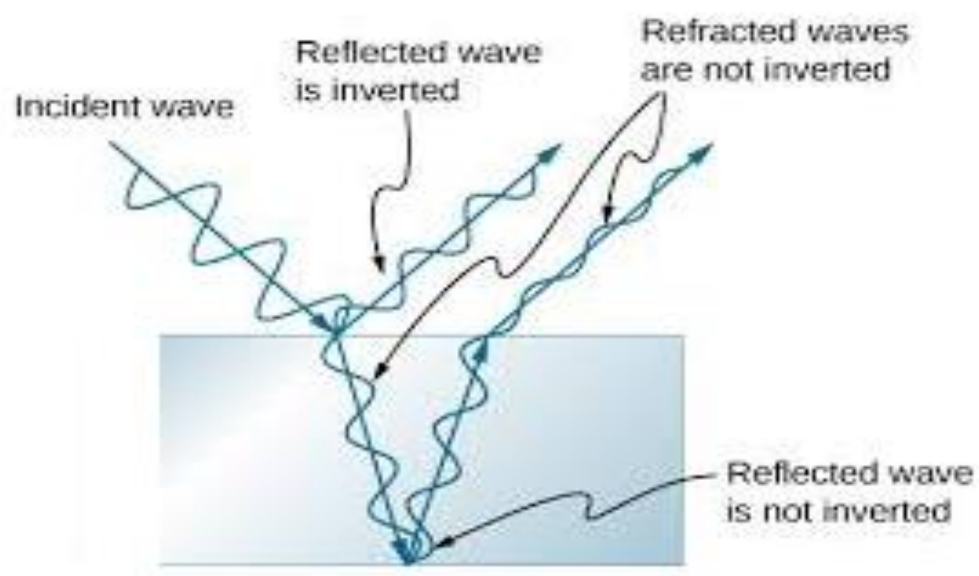
If light travels a distance of ‘t’ in an medium of refractive index ‘μ’, then its equivalent path in air or vacuum is ‘μt’.



3. Reflection of Transverse waves :

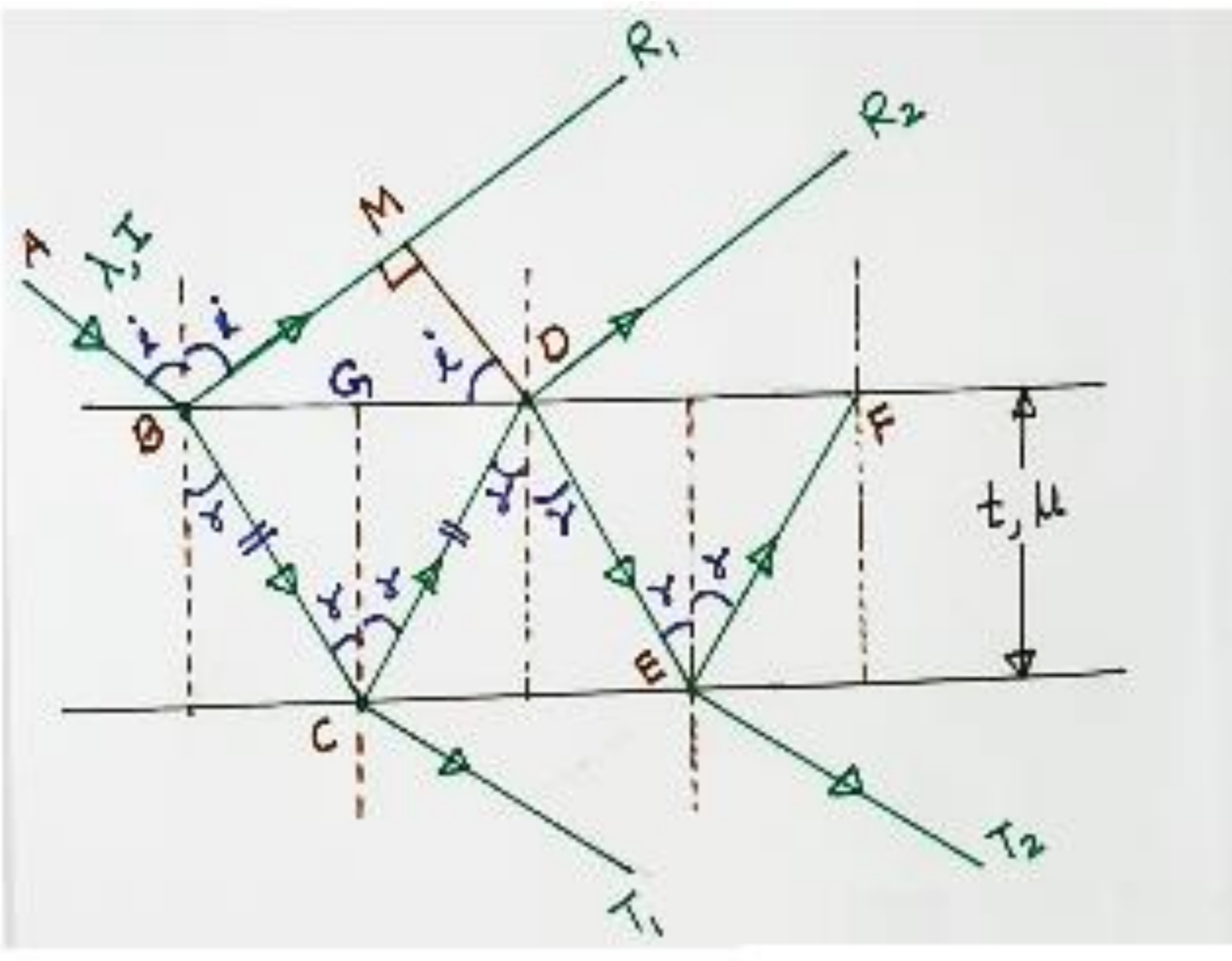
No phase or path changes due to reflection from rarer medium.

Phase changes by π radian (which is equivalent to path change of λ/2) takes place, when reflection takes place from surface of denser medium.



Interference in thin film of uniform thickness (reflected system)

Interference in thin film of uniform thickness (Reflected System)



BCD in medium of RI $\mu \Rightarrow \mu(BC+CD)$

BM in air $\Longrightarrow BM$

$\therefore$ o.p.d $= \mu(BC+CD) - BM \longrightarrow ①$

$\because BC = CD \longrightarrow 2(BC)$

$\therefore$ opd $= 2\mu(BC) - (BM) \longrightarrow ②$

$\cos r = \dfrac{CG}{BC} = \dfrac{t}{BC}$

$\therefore BC = (t)/(\cos r) \longrightarrow ③$

$\sin i = \dfrac{BM}{BD} = \dfrac{BM}{BG+GD} = \dfrac{BM}{2(BG)}$

$\because BG = GD$

$\therefore BM = 2\,BG \sin i \longrightarrow ④$

$\tan r = \dfrac{BG}{CG} = \dfrac{BG}{t} \Rightarrow BG = t\tan r \longrightarrow ⑤$

⑤ → ④

$BM = (2)(t)(\tan r)(\sin i) \longrightarrow ⑥$

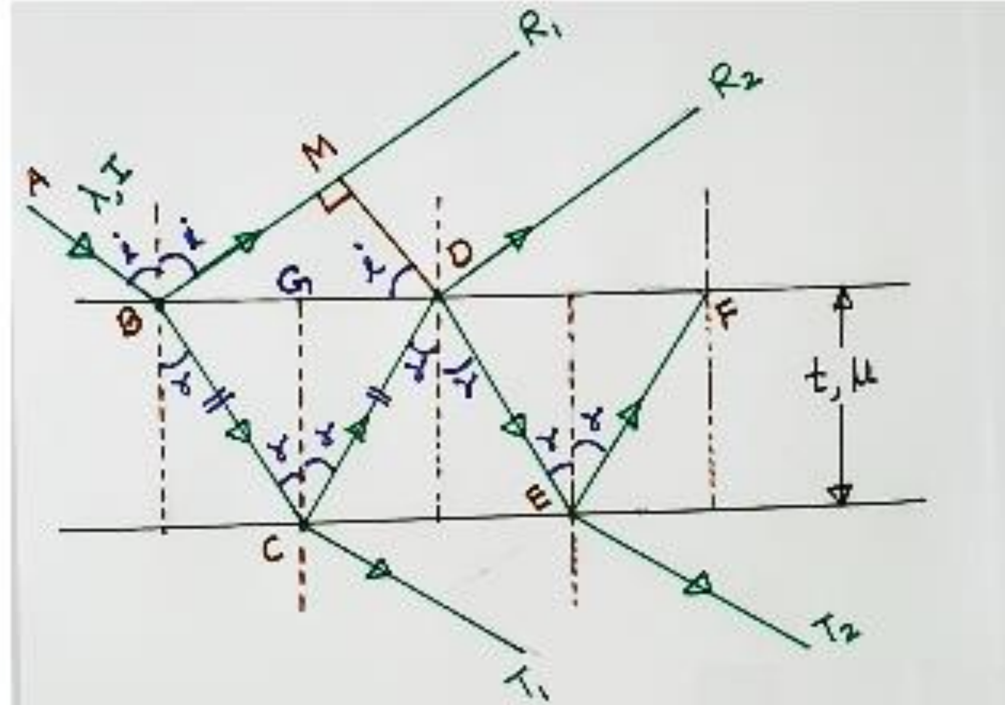
③, ⑥ → ②

opd $= 2\mu\left(\dfrac{t}{\cos r}\right) - 2t(\tan r)(\sin i)$ $\quad \sin i \to \mu$

opd $= \dfrac{2\mu t}{\cos r} - 2t\left(\dfrac{\sin r}{\cos r}\right)(\sin i)\dfrac{\sin r}{\sin r}$

opd $= \dfrac{2\mu t}{\cos r}\left(1 - \sin^2 r\right) \longrightarrow \cos^2 r$

opd $= 2\mu t\cos r \longrightarrow ⑦$



Reflection at B ⇒ at surface of denser (path changes by $\lambda/2$)

Reflection at C ⇒ at surface of rarer (no path changes)

$\therefore$ additional path changes by $(\lambda/2)$

$\therefore$ effective opd

$$\boxed{\delta = 2\mu t\cos r \pm \frac{\lambda}{2}} \longrightarrow ⑧$$

$\therefore$ effective opd

$$\boxed{\delta = 2\mu t \cos r \pm \frac{\lambda}{2}} \longrightarrow (8)$$

① <u>condition for max / bright</u>

$$\delta = n\lambda$$

$$\therefore 2\mu t \cos r + \frac{\lambda}{2} = n\lambda$$

$$2\mu t \cos r = n\lambda - \frac{\lambda}{2} = \left(\frac{2n\lambda - \lambda}{2}\right)$$

$$\boxed{2\mu t \cos r = (2n-1)\frac{\lambda}{2}} \longrightarrow (9)$$

② condition for min / dark

$$\delta = (2n \pm 1)\frac{\lambda}{2}$$

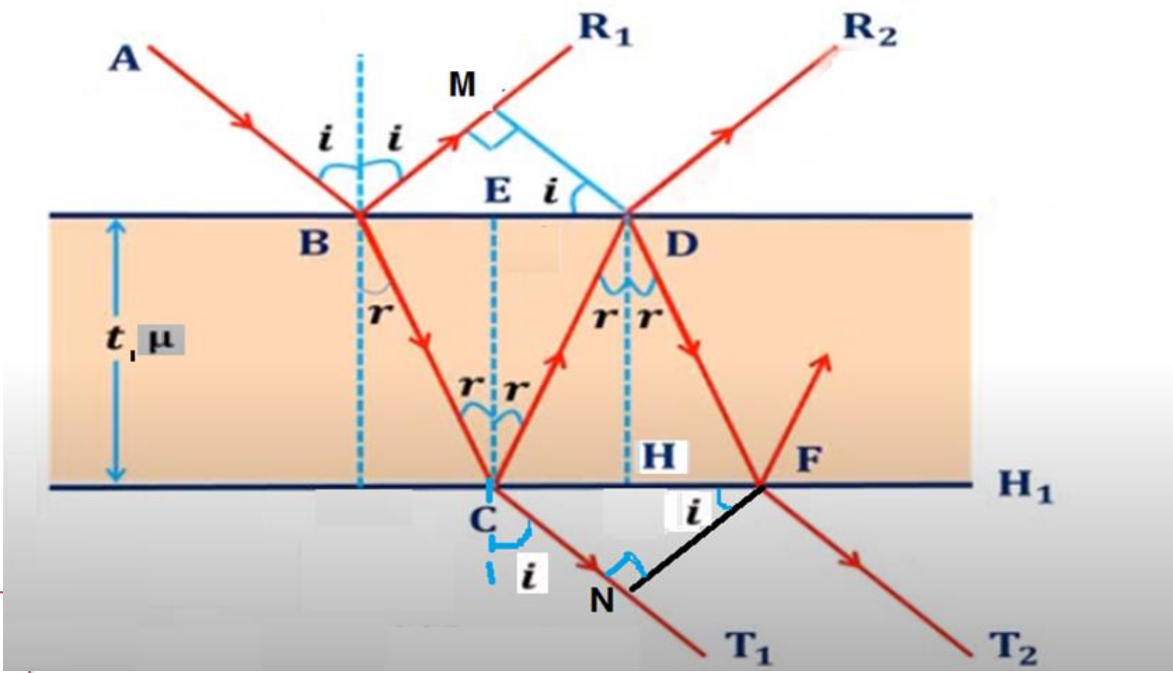
$$\therefore 2\mu t \cos r \pm \frac{\lambda}{2} = (2n \pm 1)\frac{\lambda}{2}$$

$$2\mu t \cos r \pm \frac{\lambda}{2} = (2n)\left(\frac{\lambda}{2}\right) \pm \frac{\lambda}{2}$$

$$\boxed{2\mu t \cos r = n\lambda} \longrightarrow (10)$$

Interference in thin film of uniform thickness (Transmitted System)

Interference in thin film of uniform thickness (Transmitted System)



Path difference $= 2\mu t \cos r$

net path difference $= 2\mu t \cos r$

Conditions for maxima and minima in transmitted light

The two rays BT_1 and DT_2 will reinforce each other if

$$2\mu t \cos r = n\lambda \quad \text{(condition of maxima)}$$

where $n = 1, 2, 3, \ldots$

Again the two rays will destroy each other if

$$2\mu t \cos r = (2n+1)\frac{\lambda}{2} \quad \text{(condition of minima)}$$

where $n = 0, 1, 2, \ldots$

Reflected Light

Bright Fringe

$$2\mu t \cos r = 2n \pm 1 \ \frac{\lambda}{2}$$

$$n = 0, 1, 2, 3, \ldots$$

Dark Fringe

$$2\mu t \cos r = n\lambda$$

$$n = 0, 1, 2, 3, \ldots$$

Transmitted Light

Bright Fringe

$$2\mu t \cos r = n\lambda$$

$$n = 0, 1, 2, 3, \ldots$$

Dark Fringe

$$2\mu t \cos r = 2n \pm 1 \ \frac{\lambda}{2}$$

$$n = 0, 1, 2, 3, \ldots$$

The condition of bright in reflected system is same as condition for dark in transmitted or vice-versa.

Therefore, the colours which are present in the reflected system are absent in the transmitted system.

Formation of Colours in thin films :

- We often see bright bands of colours on the surface of a soap bubble or on a thin layer of oil floating on water.

- Normally the colours are seen in the reflected system.

- The optical path difference in the reflected system is given by ($2\mu t\cos r \pm \frac{\lambda}{2}$)

- Therefore, if a film is illuminated by white light, different colours (with different wavelength) will have different optical path in the film in the given time.

- Some colours interfere constructively and due to this formation of colours take place.

- The optical path difference also depends on thickness (t) and angle of refraction (r).

- Therefore, when 't' and/or 'r' changes, optical path difference changes. This also leads to the formation of colours.

Combination of Media

Anti-reflection (AR) coating

- It is a type of optical coating applied to the surface of lenses and other optical elements to reduce reflection.

- This is also called highly refractive coating.

- This improves the efficiency since less light is lost due to reflection.

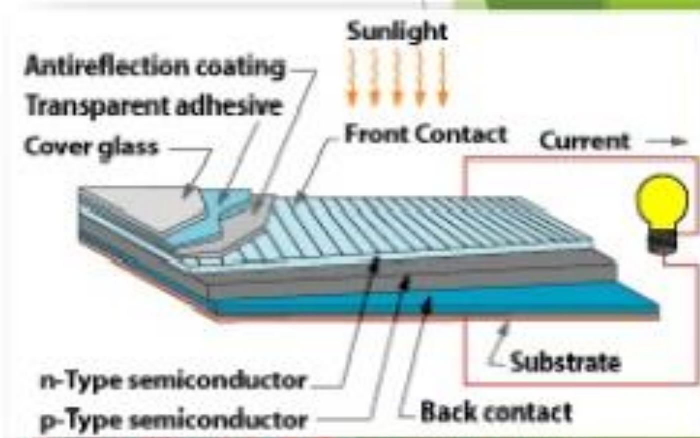
- In complex systems such as telescopes and microscopes the reduction in reflections also improves the contrast of the image by elimination of stray light.

- This is especially important in planetary astronomy. It makes the eyes of the wearer more visible to others, or a coating to reduce the glint from a covert viewer's binoculars or telescopic sight.

APPLICATION OF ANTIREFLECTION COATING

- Anti-reflection coated optical windows
- Reflex free sight glasses
- Laser scanner windows
- Contrast enhancement
- Anti glare coated instrument windows
- Sensor technology
- Low reflection camera windows
- Holography components
- Antireflection coated glass for displays
- In microelectronic photolithography to reduce image (substrate) distortions .

Glass with MgF_2 coating

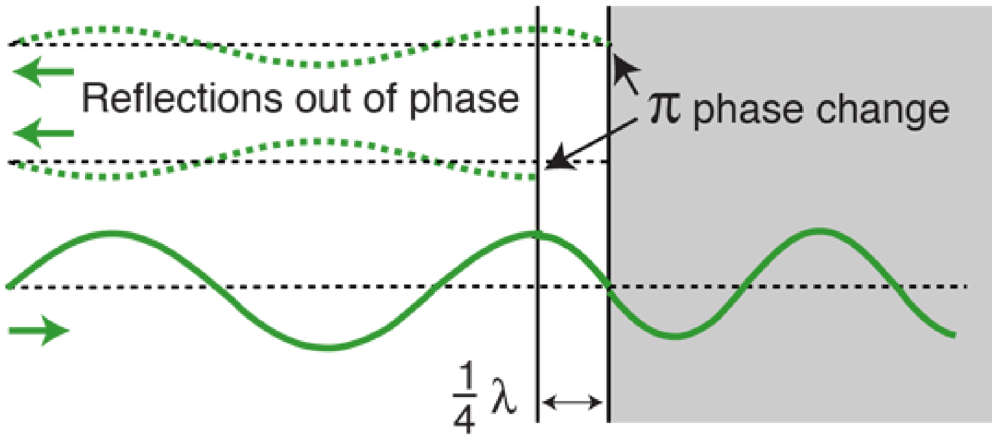


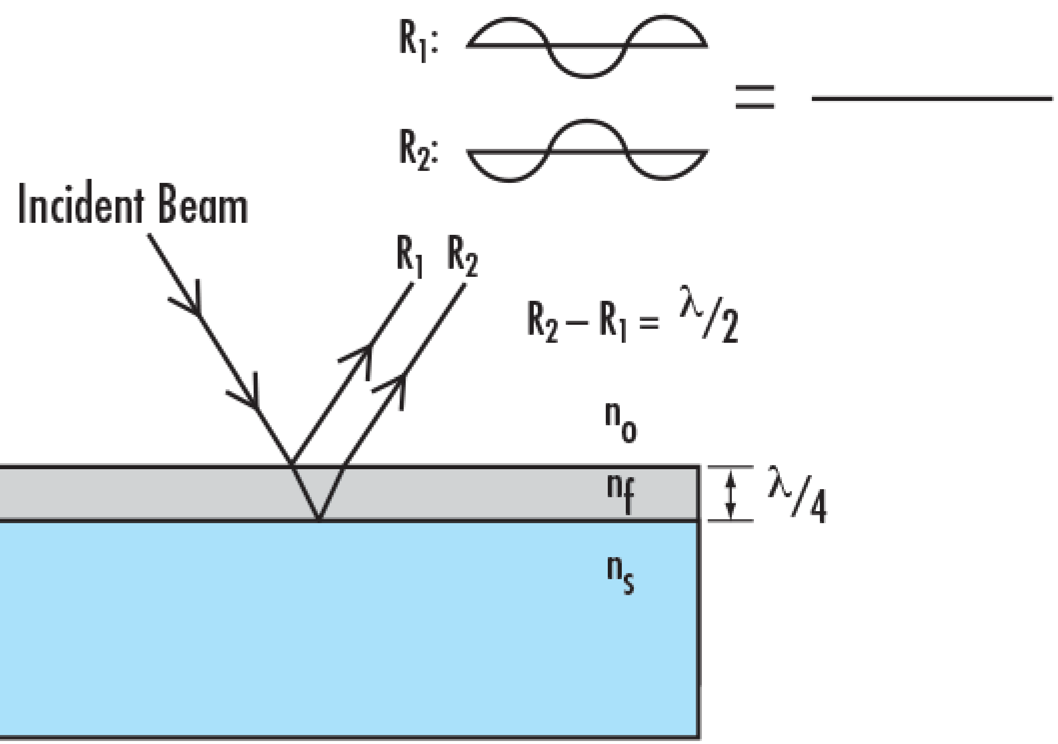
solar cell with SiO coating

Source: https://www.slideshare.net/lovecantbpainted/anti-reflective-coatings-on-the-solar-photo-voltaic-panels

Derivations for Anti-reflection (AR) coating

Anti-reflection coatings work by producing two reflections which interfere destructively with each other.





https://www.google.com/search?q=applications+of+anti+reflection+coating&rlz=1C1RLNS_enIN667IN667&sxsrf=ALeKk02pbN3aeQXuBjr8yzZEGPSpaH4jcQ:1598285253850&source=lnms&tbm=isch&sa=X&ved=2ahUKEwiwubjGnLTrAhXbxjgGHZk4B2IQ_AUoAXoECBAQAw&biw=1366&bih=657#imgrc=d4E6b1RQyYPRPM