5.3 Wave Optics

Coherence
Two-Slit Interference
Thin film Interference
Polarization

Wave Properties of Light

Wave optics or Physical optics is the study of the wave properties of light.

Some wave properties are:

Interference, diffraction, and polarization.

These properties have useful applications in optical devices such as compact discs, diffraction gratings, polarizers.

Interference Effects

Interference is a general property of waves.

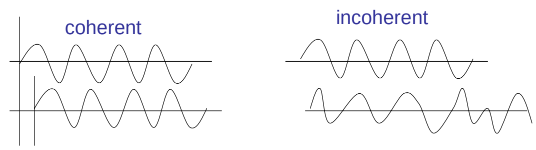
A condition for interference is that the wave source is coherent.

Interference between two waves gives characteristic interference patterns due to constructive and destructive interference.

Coherence

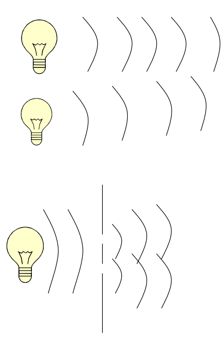
For two waves to show interference they must have coherence.

Two waves are coherent if one wave has a constant phase relation to the other



$\phi = 2\pi \frac{\Delta x}{\lambda}$ phase shift

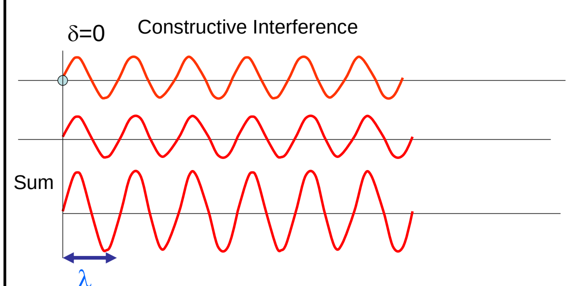
Coherence



Light from two separate light bulbs is Incoherent

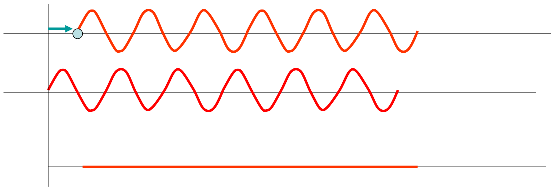
Light from a single light bulb passing through two slits is coherent

Interference



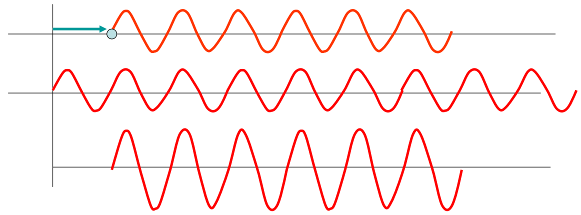
Interference

$\delta = \frac{\lambda}{2}$ Destructive Interference



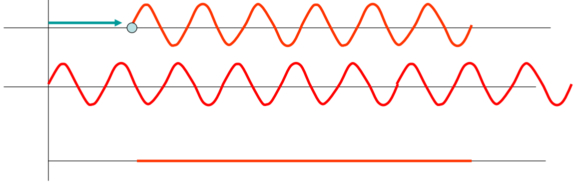
Interference

$\delta = \lambda$ Constructive Interference



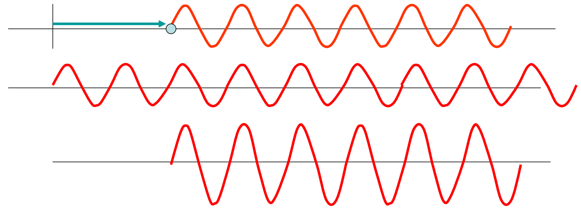
Interference

$\delta = \frac{3\lambda}{2}$ Destructive Interference

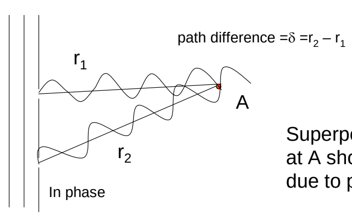


Interference

$\delta = 2\lambda$ Constructive interference



path difference



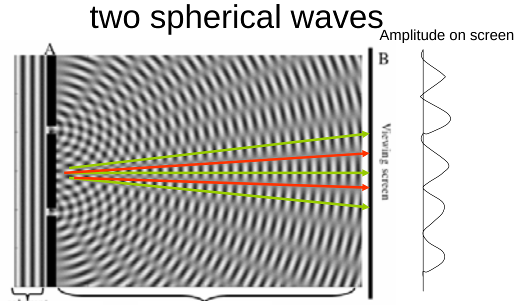
Superposition of waves at A shows interference due to path differences

Condition for constructive interference $\delta = m\lambda$

Condition for destructive interference $\delta = (m + \frac{1}{2})\lambda$

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

Interference pattern due to two spherical waves

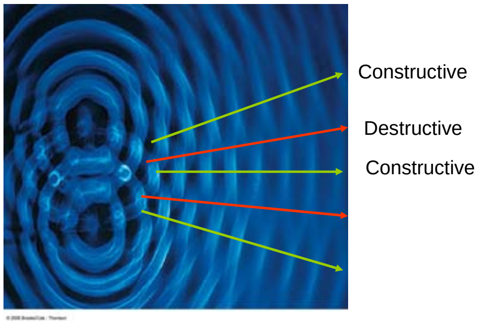


Coherent waves

Interference pattern

constructive

destructive

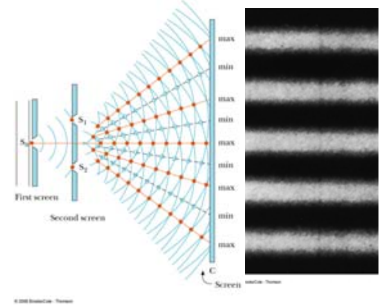


Interference pattern of water waves

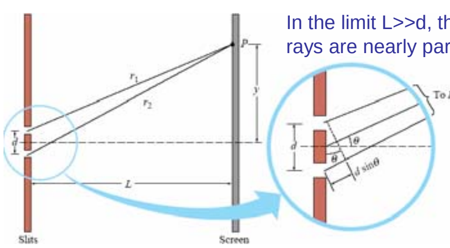
Young's two slit experiment

Thomas Young

Does light show wave properties?



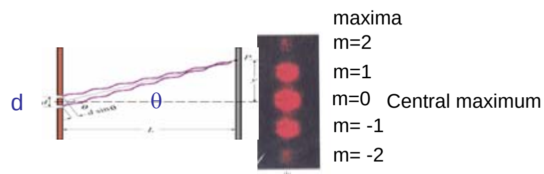
Path difference from the two slits



In the limit L>>d, the rays are nearly parallel

path difference $\delta = d\sin\theta$

Interference pattern



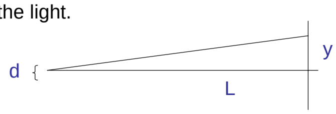
Bright
constructive interference $d\sin\theta_{bright} = m\lambda$

Dark
destructive interference $d\sin\theta_{dark} = (m + 1/2)\lambda$

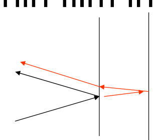
$m = 0, \pm 1, \pm 2, \ldots$

Question

Light from a laser is passed through two slits a distance of 0.10 mm apart and is hits a screen 5 m away. The separation between the central maximum and the first bright interference fringe is 2.6 cm. Find the wavelength If the light.



Thin film interference

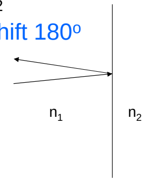


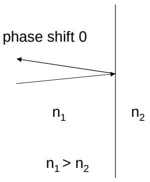
- In thin film interference the phase difference is due to reflection at either side of a thin film of transparent material.
- The phase difference is due to two factors:
  - Path difference through the film (corrected for the change in speed of light in the material)
  - Phase shift at the interface

Phase shift due to reflection

$n_1 < n_2$

phase shift 180º



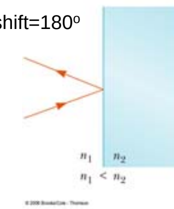


- When a wave is reflected in going from a medium with a lower refractive index to a higher refractive index the phase is shifted by π.
- When a wave is reflected in going from a medium with a higher refractive index to a lower refractive index, the phase is not shifted.

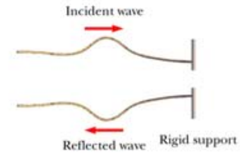
Phase shift due to reflection

$n_1 < n_2$

phase shift=180º



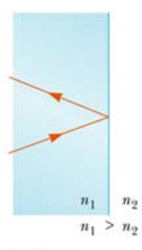
Reflection with inversion
phase shift = 180º

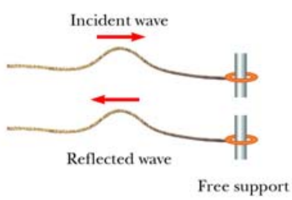


Phase shift due to reflection

$n_1 > n_2$
Phase shift = zero

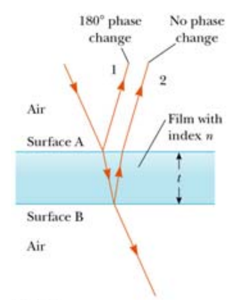
Reflection without inversion
Phase shift = zero





Thin film Interference

For a thin film in air the phase difference due to reflection is 180º



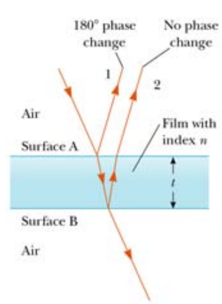
Condition for constructive interference

$$\delta=2t= (m+\frac{1}{2})\lambda_{film} = (m+\frac{1}{2})\frac{\lambda}{n}$$

The wavelength in the film is longer than in air.

Thin film Interference

For film in air the phase difference due to reflection is 180º

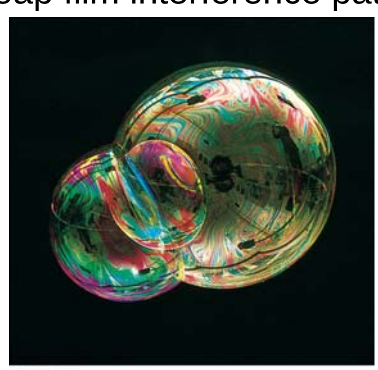


Condition for destructive interference

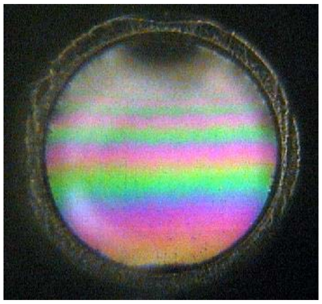
$$\delta=2t= m\lambda_{film} = m\frac{\lambda}{n}$$

The wavelength in the film is longer than in air.

Soap film interference pattern



Soap film



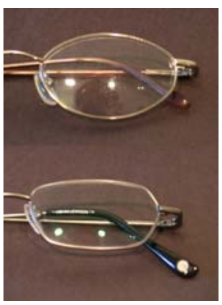
Question

A vertical soap film displays a series of colored band due to reflected light. Find the thickness of the film at the position of the 5th green band (λ=550 nm, n =1.33)

Constructive Interference
The 5th band has m=4 (the first is m=0)

Anti-reflective Coating

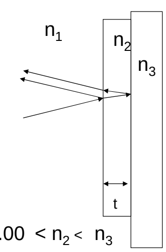
no coating



anti-reflective coating

Anti-reflective coatings are used to reduce reflections at the air-glass interface.

Anti-reflective Coating



Anti-reflective coatings consists of a thin-layer of material with a refractive index in between that of air and glass. Destructive interference between light reflected at the two surfaces reduces the intensity of reflected light.

n_1=1.00 < n_2 < n_3

phase shift of 180º at both interfaces.
Total phase difference due to reflection is zero

Condition for destructive interference.

$$2t = (m + \frac{1}{2})\frac{\lambda}{n_2}$$

Question

An anti-reflective coating of MgF_2 (n=1.38) is used on a glass surface to reduce reflections. Find the minimum thickness of the coating that can be used for green light (λ=550 nm).