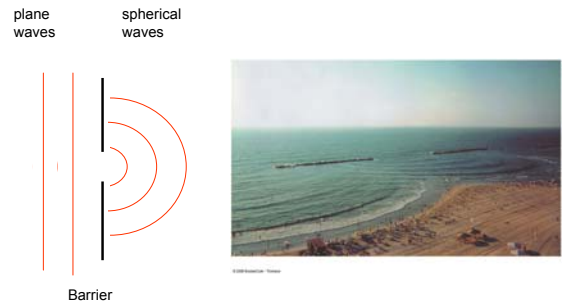


## 5.1 Wave Optics, Interference

Huygens' Principle  
 Coherence  
 Two-Slit Interference  
 Thin film Interference

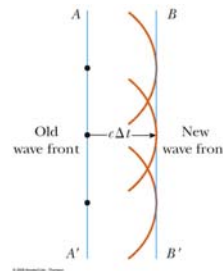
## Waves



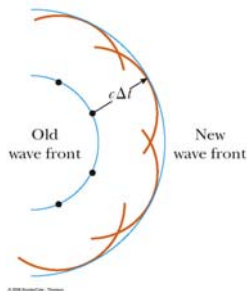
## Huygen's Principle

- All points in a given wave front are taken as point sources for the production of spherical secondary wavelets which propagate in space. After some time the new wave front is the tangent to the wavelets.

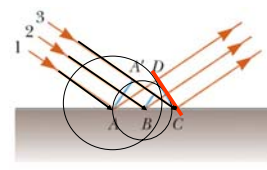
## Huygen's Picture of a Plane wave



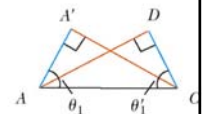
## Huygen's Picture of a Spherical wave



## Huygen's Explanation of Reflection

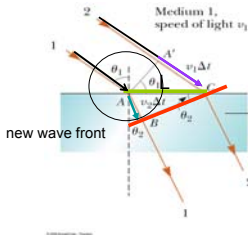


$$\theta_1 = \theta'_1$$



two sides and an angle equal  
 $\therefore$  similar triangles

## Huygen's explanation for Refraction



$$\sin\theta_1 = \frac{v_1 t}{L}$$

$$\sin\theta_2 = \frac{v_2 t}{L}$$

$$\frac{1}{v_1} \sin\theta_1 = \frac{1}{v_2} \sin\theta_2$$

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

## Interference Effects

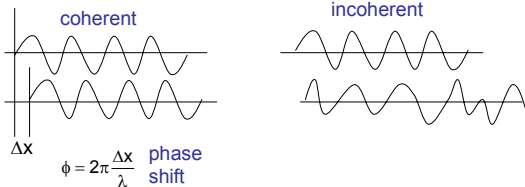
Interference is a general property of waves. A condition for interference is that the wave source is **coherent**.

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

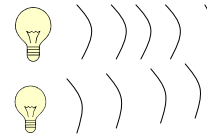
## Coherence

For two waves to show interference they must have coherence.

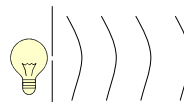
Two waves are coherent if one wave has a constant phase relation to the other



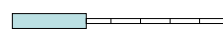
## Coherence



Light from two separate light bulbs is Incoherent

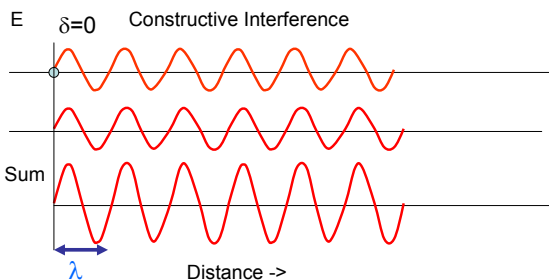


Light from a single light bulb passing through a small slit is coherent

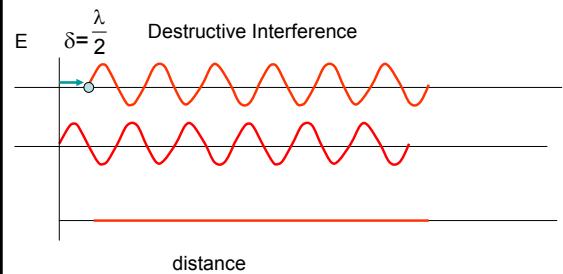


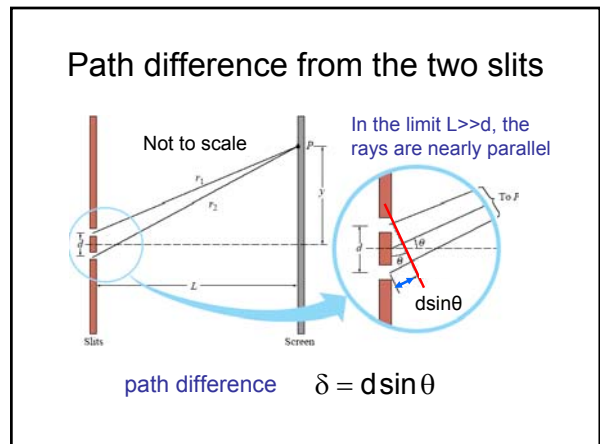
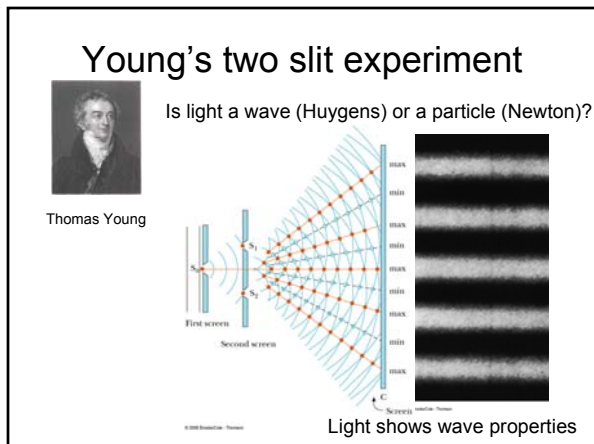
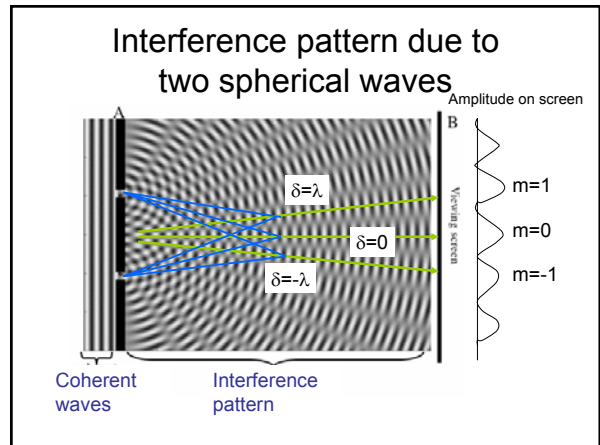
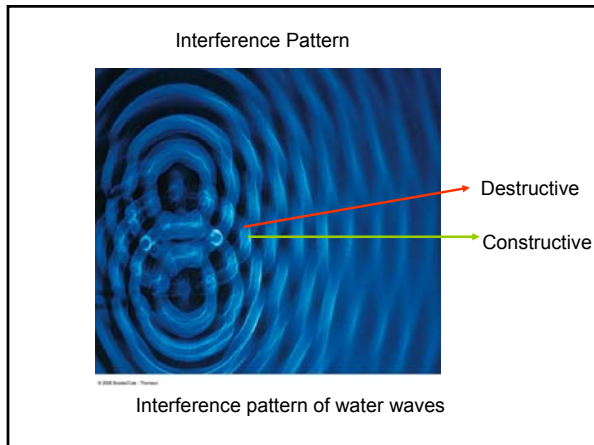
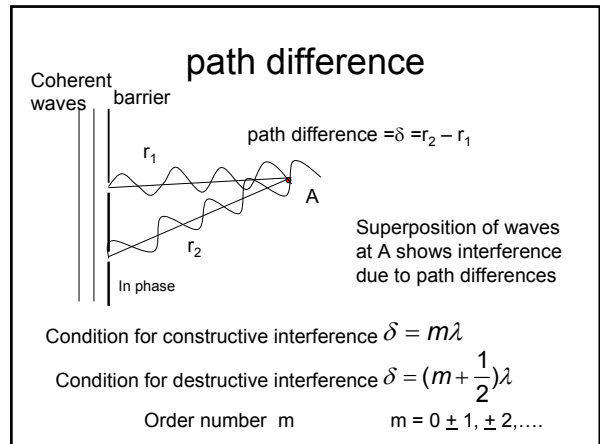
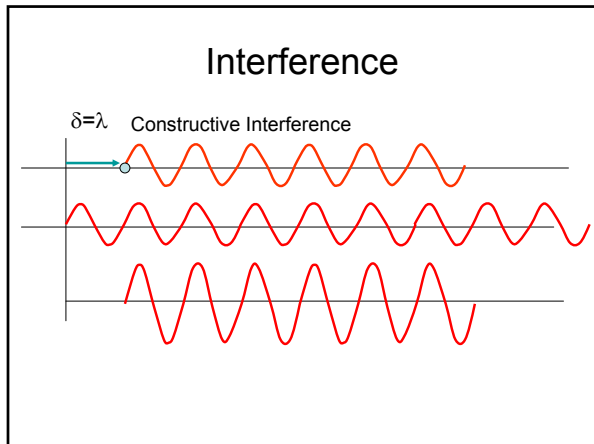
Laser light is coherent

## Interference



## Interference





### Interference pattern

maxima  
m=2  
m=1  
m=0 Central maximum  
m=-1  
m=-2

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

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

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

### Wavelength of light

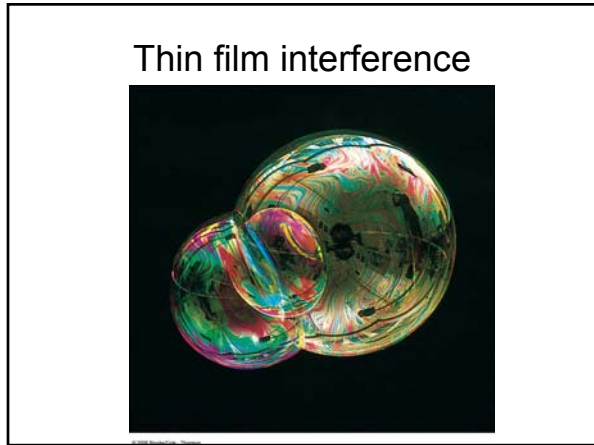
Light from a laser is passed through two slits a distance of 0.10 mm apart and is hits a screen 5.0 m away. The separation between the central maximum and the first bright interference fringe is 2.6 cm. Find the wavelength of the light.

0.10mm  $d$   $\theta$   $L$  5.0 m  $y$   $m=1$   $m=0$  2.6 cm

$d \sin \theta = m\lambda$  for small angles  $\sin \theta \approx \tan \theta \approx \frac{y}{L}$

$\Rightarrow d \frac{y}{L} = m\lambda$  solve for  $\lambda$  for  $m=1$

$\lambda = \frac{yd}{mL} = \frac{(2.6 \times 10^{-2} \text{ m})(0.1 \times 10^{-3} \text{ m})}{(1)(5.0 \text{ m})} = 5.2 \times 10^{-7} \text{ m} = 520 \text{ nm}$



### Thin film interference

- In thin film interference is interference between light reflected from front and back surfaces of a thin film.
- 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 due to reflection at the interface

### Phase shift due to reflection

$n_1 < n_2$   
phase shift =  $180^\circ$

Reflection with inversion  
phase shift =  $180^\circ$

### Phase shift due to reflection

$n_1 > n_2$   
Phase shift = zero

Reflection without inversion  
Phase shift = zero

## Thin film Interference

Interference between light reflected from Top and bottom surfaces.

For a film in air the phase difference due to reflection is  $180^\circ$ .

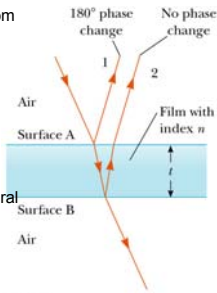
If the path difference ( $2t$ ) is negligible then there is **destructive** interference.

Destructive interference occurs when the path length difference equals integral multiples of the wavelength.

Condition for **destructive** interference

$$\delta = 2t = m\lambda_{\text{film}} = m\frac{\lambda}{n} \quad \text{The wavelength in the film is shorter than in air.}$$

$m=0, 1, 2, 3, \dots$



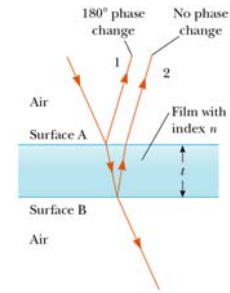
## Thin film Interference for a soap film in air

For **constructive** interference the path difference ( $2t$ ) must be half integral multiples of the wavelength to make up for the phase shift on reflection.

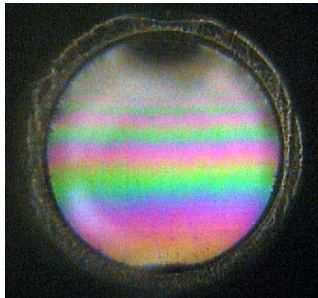
Condition for **constructive** interference

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

$m=0, 1, 2, 3, \dots$



## 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 3<sup>rd</sup> green band from the top ( $\lambda=550 \text{ nm}$ ,  $n=1.33$ )

Constructive Interference  
 $2t = (m + \frac{1}{2})\frac{\lambda}{n}$



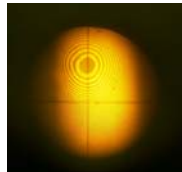
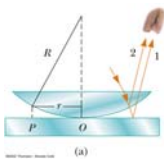
$$2t = 1/2 (\lambda/n) \quad m=0$$

$$2t = 3/2 (\lambda/n) \quad m=1$$

$$2t = 5/2 (\lambda/n) \quad m=2$$

$$t = (m + \frac{1}{2})\frac{\lambda}{2n} = (2 + \frac{1}{2})\frac{550\text{nm}}{2(1.33)} = 517\text{nm}$$

## Newton's rings



Interference due to reflected light from two surfaces of the thin film of air.

Why is it dark in the middle?

## Anti-reflective Coating

no coating

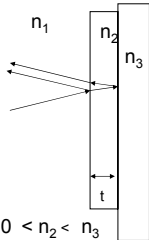


Anti-reflective coatings are used to reduce reflections at the air-glass interface.

anti-reflective coating



## 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.

What is the condition for destructive interference?

- $n_1=1.00 < n_2 < n_3$
- There is a phase shift of  $180^\circ$  at both interfaces.
  - The phase difference due to reflection is zero
  - The path difference must be a half-integral number of wavelengths.

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

## Question

An anti-reflective coating of  $\text{MgF}_2$  ( $n=1.38$ ) is used on a glass surface to reduce reflections. Find the minimum thickness of the coating that can be used for green light ( $\lambda=550 \text{ nm}$ ).

For destructive interference

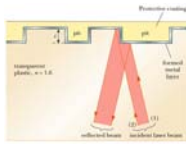
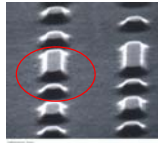
$$2t = \left(m + \frac{1}{2}\right) \frac{\lambda}{n_2} \quad \text{minimum at } m=0 \Rightarrow 2t = \frac{1}{2} \frac{\lambda}{n}$$

Solve for t

$$t = \frac{\lambda}{4n} = \frac{550 \text{ nm}}{4(1.38)} = 100 \text{ nm}$$

Quarter wavelength (in coating) thickness

## Optical compact disc



A CD stores information in a series of pits and bumps in the plastic. The information is read by a reflected laser beam. The intensity of the beam is changed by destructive interference of the reflected light

$$t = \frac{\lambda}{4n}$$

destructive interference