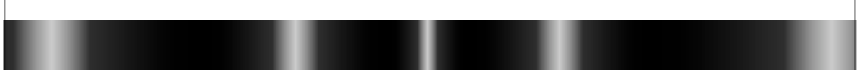
Physics 1402: Lecture 33
Today's Agenda

- **Announcements:**
  - **Midterm 2: graded after Thanks Giving**
  - **Homework 09: Friday December 4**
- **Optics**
  - **interference**

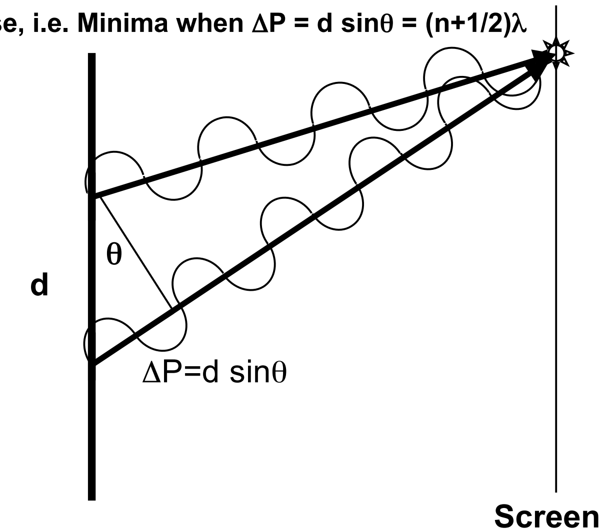
Interference



A wave through two slits

In Phase, i.e. Maxima when $\Delta P = d \sin\theta = n\lambda$

Out of Phase, i.e. Minima when $\Delta P = d \sin\theta = (n+1/2)\lambda$



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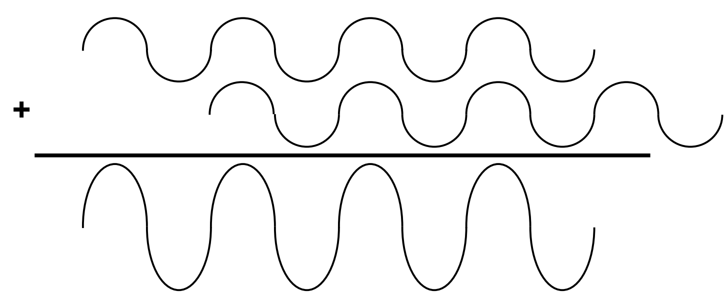
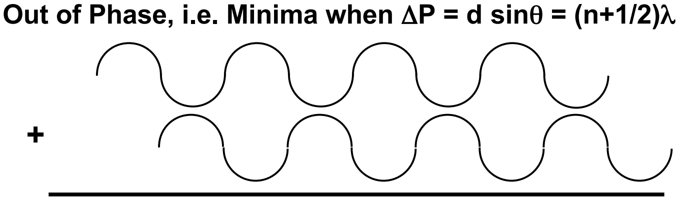


Out of Phase, i.e. Minima when $\Delta P = d \sin\theta = (n+1/2)\lambda$

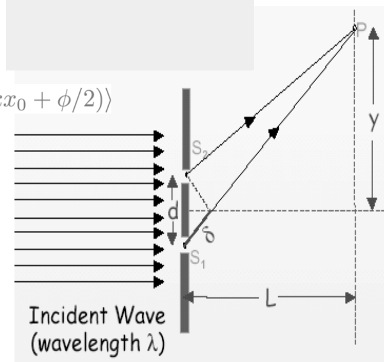


Lecture 4

The Intensity

What is the intensity at P?

$$I_P = \langle A_P^2 \rangle = \langle 4A_{\max}^2 \cos^2(\phi/2) \sin^2(\omega t + kx_0 + \phi/2) \rangle$$



The only term with a t dependence is $\sin^2($ $)$.That term averages to ½ .

$$I_P = 2A_{\max}^2 \cos^2(\phi/2)$$

If we had only had one slit, the intensity would have been,

$$I_1 = \langle A_{\max}^2 \sin^2(\omega t + kx_0) \rangle = \frac{1}{2} A_{\max}^2$$

So we can rewrite the total intensity as,

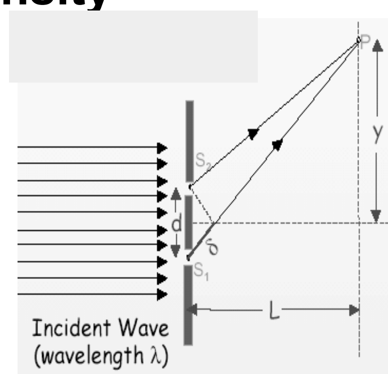
$$I_P = 4I_1 \cos^2(\phi/2) \quad \textbf{with} \quad \phi = k\delta = 2\pi \frac{\delta}{\lambda}$$

The Intensity

We can rewrite intensity at point P in terms of distance y

$$\sin\theta \approx \frac{y}{L}$$

$$\delta = d \sin\theta \approx \frac{d \cdot y}{L}$$



Using this relation, we can rewrite expression for the intensity at point P as function of y

$$I_P = 4I_1 \cos^2(\phi/2) = 4I_1 \cos^2\left(\frac{\pi d}{\lambda L} y\right)$$

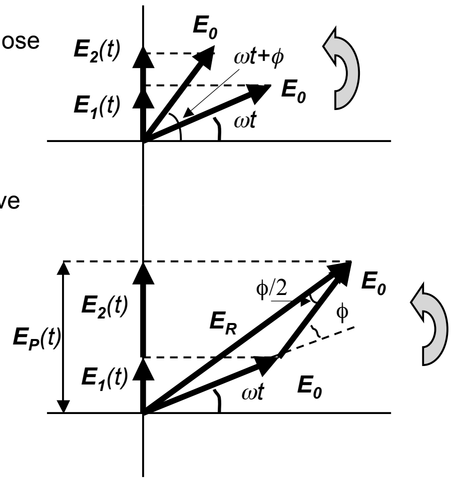
Constructive interference occurs at $y = \frac{\lambda L}{d} m$

where m=+/-1, +/-2 …

Phasor Addition of Waves

Consider a sinusoidal wave whose electric field component is

$$E_1(t) = E_0 \sin(\omega t)$$



Consider second sinusoidal wave

$$E_2(t) = E_0 \sin(\omega t + \phi)$$

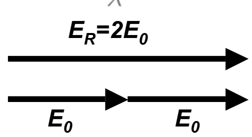
The projection of sum of two phasors E_P is equal to

$$E_R = 2E_0 \cos(\phi/2)$$

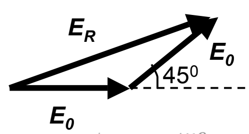
$$\begin{aligned} E_P(t) &= E_1(t) + E_2(t) = E_R \sin(\omega t + \phi/2) \\ &= 2E_0 \cos(\phi/2) \sin(\omega t + \phi/2) \end{aligned}$$

Phasor Diagrams for Two Coherent Sources

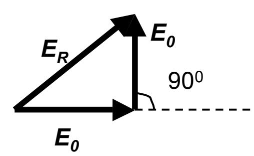
$$\phi = k\delta = 2\pi \frac{\delta}{\lambda}$$



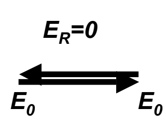
$$\begin{aligned} \phi &= 0 \\ \delta &= 0 \end{aligned}$$



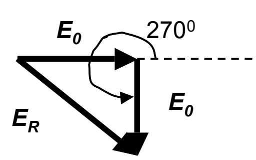
$$\begin{aligned} \phi &= 45^o \\ \delta &= \lambda/8 \end{aligned}$$



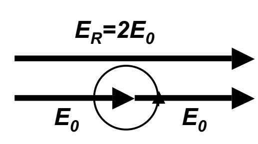
$$\begin{aligned} \phi &= 90^o \\ \delta &= \lambda/4 \end{aligned}$$



$$\begin{aligned} \phi &= 180^o \\ \delta &= \lambda/2 \end{aligned}$$



$$\begin{aligned} \phi &= 270^o \\ \delta &= 3\lambda/4 \end{aligned}$$

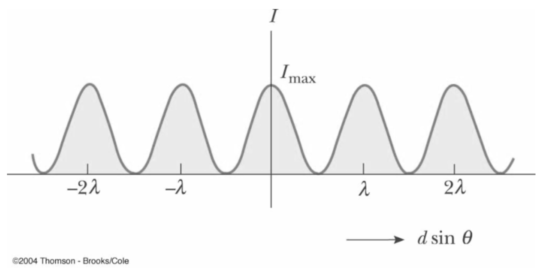


$$\begin{aligned} \phi &= 360^o \\ \delta &= \lambda \end{aligned}$$

Lecture 4

SUMMARY

2 slits interference pattern (Young's experiment)

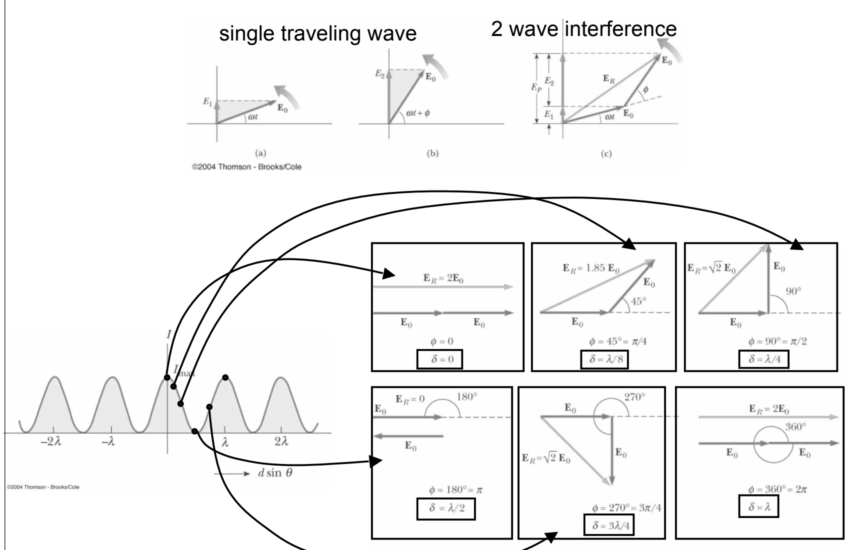


How would pattern be changed if we add one or more slits ?
(assuming the same slit separation)

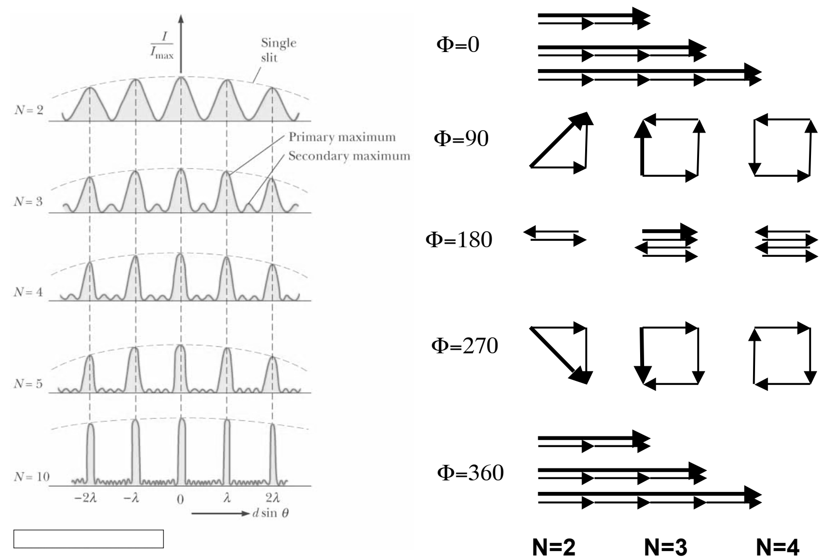
3 slits, 4 slits, 5 slits, etc.

Phasor: 1 vector represents 1 traveling wave

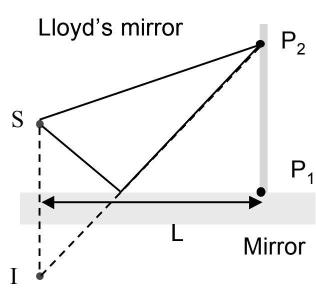
single traveling wave 2 wave interference



N-slits Interference Patterns



Change of Phase Due to Reflection



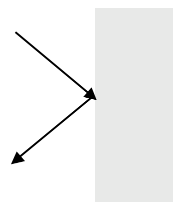
The reflected ray (red) can be considered as an original from the image source at point I. Thus we can think of an arrangement S and I as a double-slit source separated by the distance between points S and I.

An interference pattern for this experimental setting is really observed …..
but dark and bright fringes are reversed in order

This mean that the sources S and I are different in phase by 180^0

An electromagnetic wave undergoes a phase change by 180^0 upon reflecting from the medium that has a higher index of refraction than that one in which the wave is traveling.

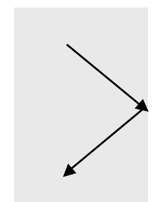
Change of Phase Due to Reflection



n_1 n_2

180^0 phase change

$n_1<n_2$

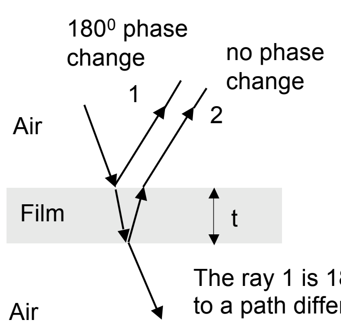


n_1 n_2

no phase change

$n_1>n_2$

Interference in Thin Films



A wave traveling from air toward film undergoes 180^0 phase change upon reflection.
The wavelength of light λ_n in the medium with refraction index n is

$$\lambda_n = \frac{\lambda}{n}$$

The ray 1 is 180^0 out of phase with ray 2 which is equivalent to a path difference $\lambda_n/2$.
The ray 2 also travels extra distance 2t.

Constructive interference

$$2t = (m + \frac{1}{2})\lambda_n = (m + \frac{1}{2})\frac{\lambda}{n} \text{ where } m = 0, 1, 2, \ldots$$

Destructive interference

$$2t = m\lambda_n = m\frac{\lambda}{n} \text{ where } m = 0, 1, 2, \ldots$$

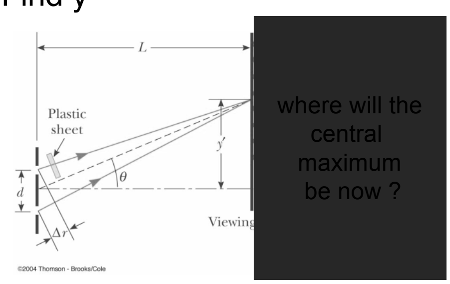
Chapter 33 – Act 1

Estimate minimum thickness of a soap-bubble film (n=1.33) that results in constructive interference in the reflected light if the film is Illuminated by light with λ=600nm.

A) 113nm B) 250nm C) 339nm

Problem

Consider the double-slit arrangement shown in Figure below, where the slit separation is d and the slit to screen distance is L. A sheet of transparent plastic having an index of refraction n and thickness t is placed over the upper slit. As a result, the central maximum of the interference pattern moves upward a distance y'. Find y'

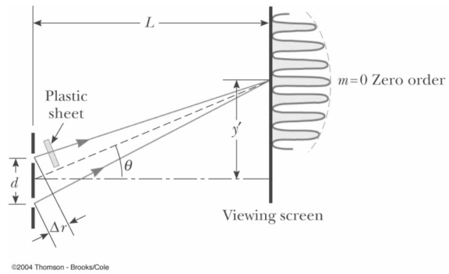


Lecture 4

Solution

Phase difference for going though plastic sheet:

$$\phi = 2\pi \left(\frac{t}{\lambda_a}\right)(n-1)$$



Corresponding path length difference:

$$\Delta r = \phi\left(\frac{\lambda_a}{2\pi}\right) = 2\pi\left(\frac{t}{\lambda_a}\right)(n-1)\left(\frac{\lambda_a}{2\pi}\right) = t(n-1)$$

Angle of central max is approx:

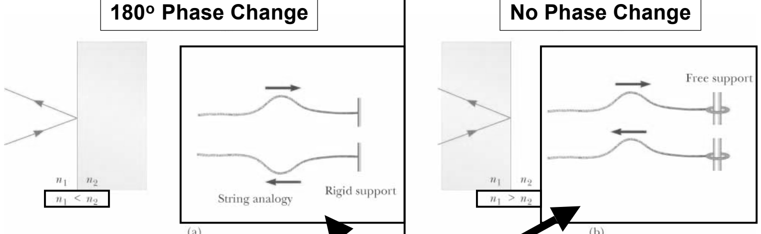
$$\tan\theta = \frac{\Delta r}{d} = \frac{y'}{L}$$

Thus the distance y' is:

$$\frac{y'}{L} = \frac{t(n-1)}{d}$$ gives $$y' = \frac{t(n-1)L}{d}$$

Phase Change upon Reflection from a Surface/Interface

Reflection from Optically Denser Medium (larger n)	Reflection from Optically Lighter Medium (smaller n)
180º Phase Change	**No Phase Change**



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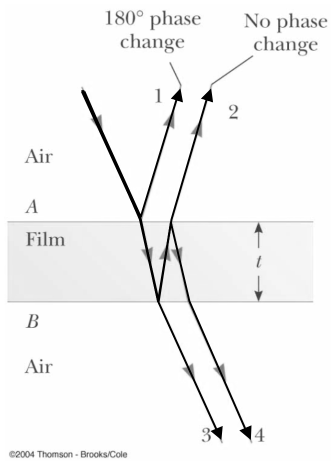
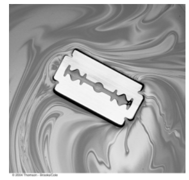
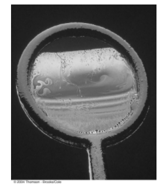
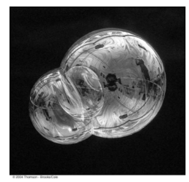
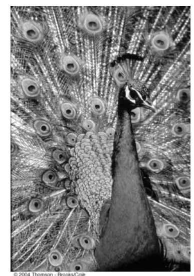
by analogy to reflection of traveling wave in mechanics

constructive: 2t = (m +1/2) λ_n
destructive: 2t = m λ_n



constructive: 2t = m λ_n
destructive: 2t = (m +1/2) λ_n

Examples :

Application

Reducing Reflection in Optical Instruments