UFUG 1504: Honors General Physics II

Chapter 35

Interference

35 Summary (1 of 5)

Huygen's Principle

- The three-dimensional transmission of waves, including light, may often be predicted by Huygens' principle, which states that all points on a wavefront serve as point sources of spherical secondary wavelets.

Wavelength and Index of Refraction

- The wavelength λ_n of light in a medium depends on the index of refraction n of the medium:

$$\lambda_n = \frac{\lambda}{n}, \qquad \textbf{Equation (35-6)}$$

in which λ is the wavelength in vacuum.

35 Summary (2 of 5)

Young's Experiment

- In Young's interference experiment, light passing through a single slit falls on two slits in a screen. The light leaving these slits flares out (by diffraction), and interference occurs in the region beyond the screen. A fringe pattern, due to the interference, forms on a viewing screen.
- The conditions for maximum and minimum intensity are

$$d \sin \theta = m\lambda, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{minima} - \text{bright fringes}),$$ **Equation (35-14)**

$$d \sin \theta = \left(m + \frac{1}{2}\right)\lambda, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{minima} - \text{dark fringes}),$$ **Equation (35-16)**

35 Summary (3 of 5)

Coherence

- If two light waves that meet at a point are to interfere perceptibly, both must have the same wavelength and the phase difference between them must remain constant with time; that is, the waves must be coherent.

Intensity in Two-Slit Interference

- In Young's interference experiment, two waves, each with intensity I_0, yield a resultant wave of intensity I at the viewing screen, with

$$I = 4I_0 \cos^2 \frac{1}{2}\phi, \quad \text{where } \phi = \frac{2\pi d}{\lambda}\sin\theta.$$

Equation (35-22 & 23)

35 Summary (4 of 5)

Thin-Film Interference

- When light is incident on a thin transparent film, the light waves reflected from the front and back surfaces interfere. For near-normal incidence, the wavelength conditions for maximum and minimum intensity of the light reflected from a film of index n_2 in air are

$$2L = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_2}, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{maxima} - \text{bright film in air}),$$ **Equation (35-36)**

$$2L = m\frac{\lambda}{n_2}, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{minima} - \text{dark film in air}),$$ **Equation (35-37)**

35 Summary (5 of 5)

Michelson's Interferometer

- In Michelson's interferometer a light wave is split into two beams that, after traversing paths of different lengths, are recombined so they interfere and form a fringe pattern.

35-1 Light as a Wave (5 of 9)

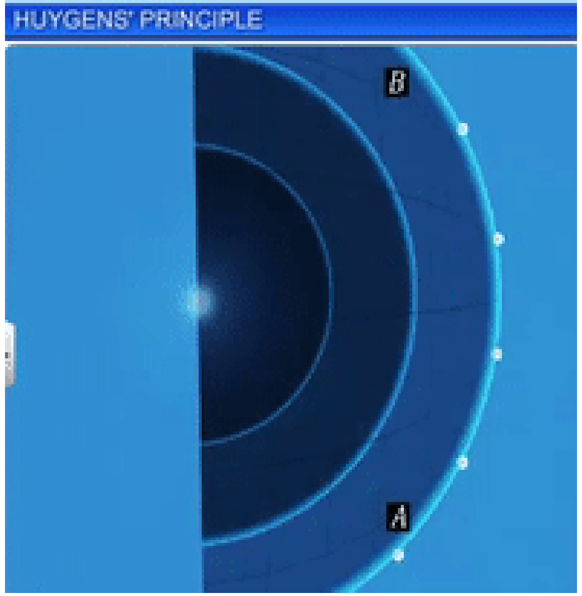
The three-dimensional transmission of waves, including light, may often be predicted by Huygens' principle (惠更斯原理), which states that

All points on a wavefront serve as point sources of spherical secondary wavelets. After a time *t*, the new position of the wavefront will be that of a surface tangent to these secondary wavelets.

35-1 Light as a Wave (6 of 9)

Huygens' principle (惠更斯原理):

All points on a wavefront serve as point sources of spherical secondary wavelets. After a time *t*, the new position of the wavefront will be that of a surface tangent to these secondary wavelets.



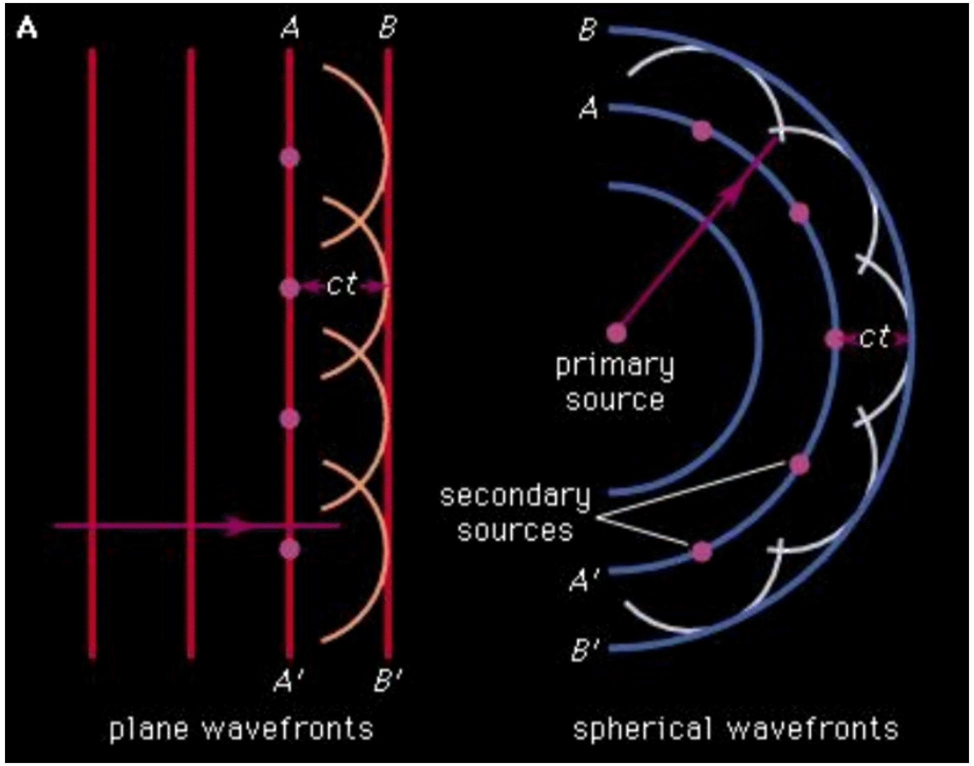
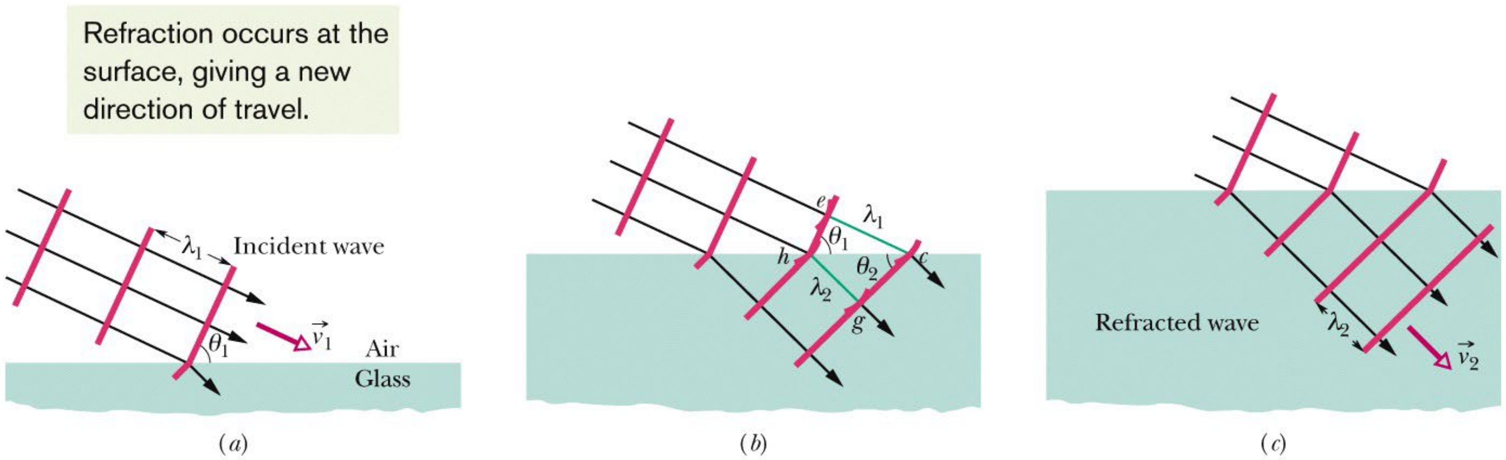
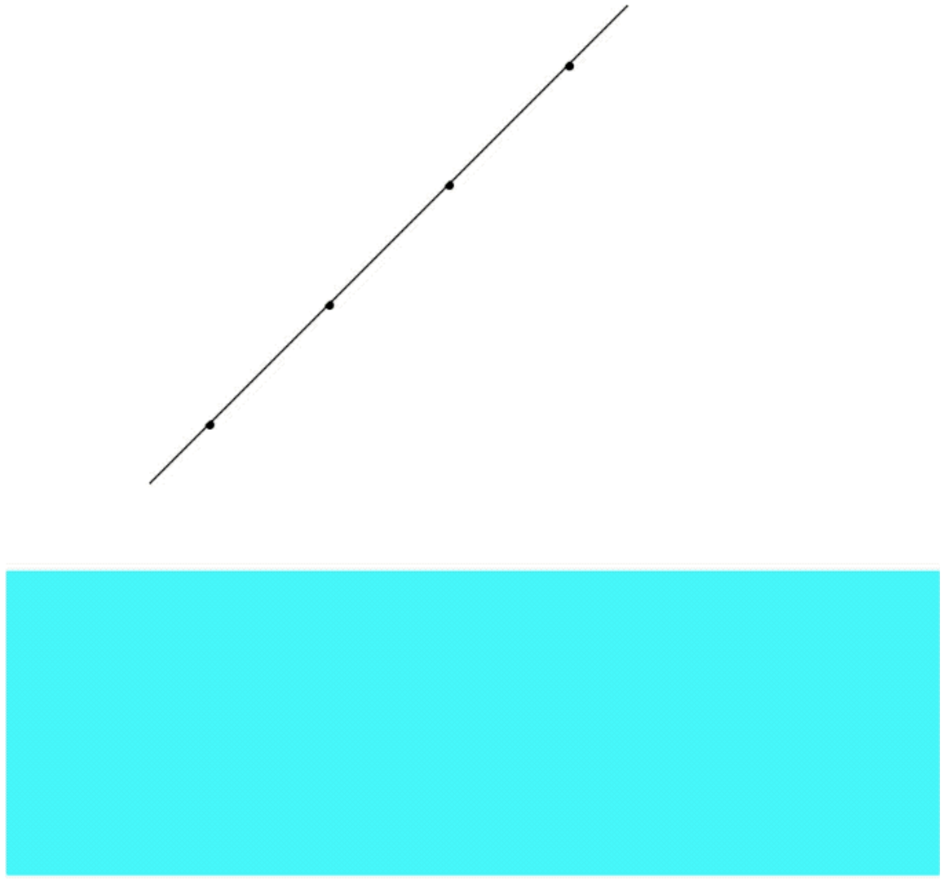


Figure 1 shows the propagation of a plane wave in vacuum, as portrayed by Huygens' principle.

35-1 Light as a Wave (7 of 9)





The refraction of a plane wave at an air–glass interface, as portrayed by Huygens' principle. The wavelength in glass is smaller than that in air. For simplicity, the reflected wave is not shown. Parts (*a*) through (*c*) represent three successive stages of the refraction.

35-1 Light as a Wave (9 of 9)

The law of refraction can be derived from Huygens' principle by assuming that the index of refraction (折射率) of any medium is

$$n = \frac{c}{v},$$

in which v is the speed of light in the medium and c is the speed of light in vacuum.

A greater index of refraction means a smaller speed

law of refraction

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

33-5 Reflection and Refraction (7 of 11)

Law of refraction: A refracted ray lies in the plane of incidence and has an angle of refraction θ_2 that is related to the angle of incidence θ_1 by

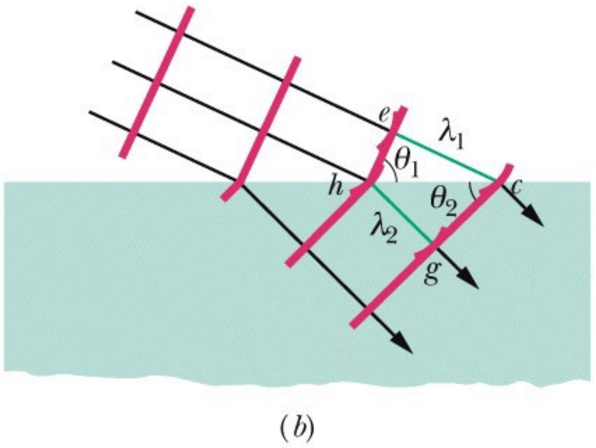
$$n_2 \sin\theta_2 = n_1 \sin\theta_1$$

Here each of the symbols n_1 and n_2 is a dimensionless constant, called the **index of refraction 折射率**, that is associated with a medium involved in the refraction.

35-1 Light as a Wave (7 of 9)

same time interval

$$\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$



(b)

ved.

For the right triangles hce and hcg

$$\sin\theta_1 = \frac{\lambda_1}{hc} \quad \text{(for triangle } hce\text{)}$$

$$\sin\theta_2 = \frac{\lambda_2}{hc} \quad \text{(for triangle } hcg\text{)}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$

$$n = \frac{c}{v},$$

$$n_1 = \frac{c}{v_1} \quad \text{and} \quad n_2 = \frac{c}{v_2}.$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1}$$

law of refraction

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

35-1 Light as a Wave (9 of 9)

The wavelength λ_n of light in a medium depends on the index of refraction n of the medium:

$$\lambda_n = \frac{\lambda}{n}, \quad \text{where } \lambda \text{ is the wavelength of vacuum}$$

A greater index of refraction means a smaller wavelength

although the speed and wavelength of light in the medium are different from what they are in vacuum, *the frequency of the light in the medium is the same as it is in vacuum.*

$$f_n = \frac{v}{\lambda_n} = \frac{c/n}{\lambda/n} = \frac{c}{\lambda} = f.$$

35-1 Light as a Wave (9 of 9)

Because of this dependency $\lambda_n = \frac{\lambda}{n}$, the phase difference between two waves can change if they pass through different materials with different indexes of refraction.

The difference in indexes causes a phase shift between the rays.

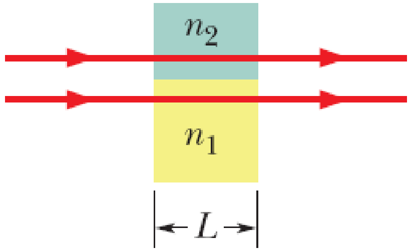


Figure 35-4 Two light rays travel through two media having different indexes of refraction.

we first count the number N_1 of wavelengths there are in the length L of medium 1.

$$\lambda_{n1} = \lambda / n_1 \Rightarrow N_1 = \frac{L}{\lambda_{n1}} = \frac{Ln_1}{\lambda}$$

Similarly

$$N_2 = \frac{L}{\lambda_{n2}} = \frac{Ln_2}{\lambda}$$

new phase difference

$$N_2 - N_1 = \frac{Ln_2}{\lambda} - \frac{Ln_1}{\lambda} = \frac{L}{\lambda}(n_2 - n_1)$$

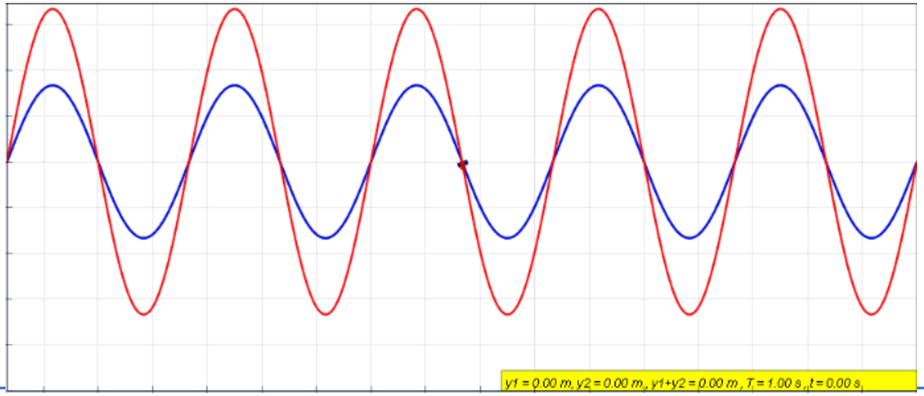
35-1 Light as a Wave (9 of 9)

Path Length Difference

the path length difference ΔL compares to the wavelength λ of the waves

maximum brightness $$\frac{\Delta L}{\lambda} = 0, 1, 2, \ldots \quad \text{(fully constructive interference).}$$

darkness $$\frac{\Delta L}{\lambda} = 0.5, 1.5, 2.5, \ldots \quad \text{(fully destructive interference).}$$

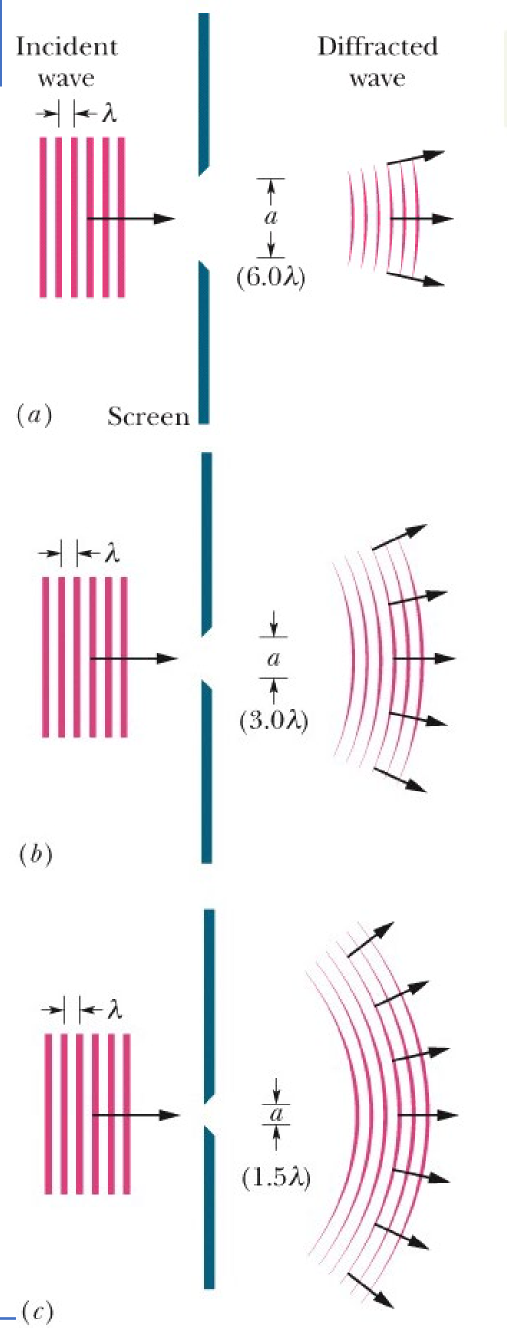


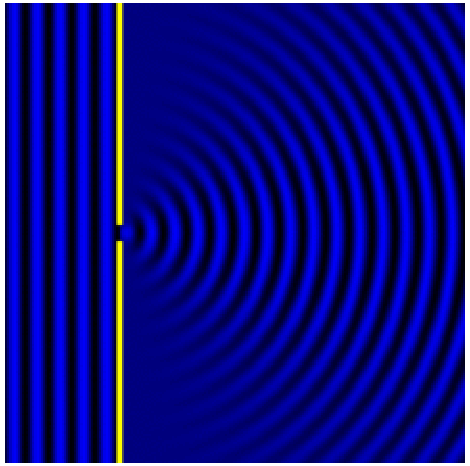
35-2 Young's Interference (4 of 8)

Diffraction (衍射) occurs for waves of all types, not just light waves. Figure below shows waves passing through a slit (狭缝) flares.

Figure (a) shows the situation schematically for an incident plane wave of wavelength λ encountering a slit that has width $a = 6.0\ \lambda$ and extends into and out of the page. The part of the wave that passes through the slit flares out on the far side.

Figures (b) (with $a = 3.0\ \lambda$) and $(c)(a = 1.5\lambda)$ illustrate the main feature of diffraction: the narrower the slit, the greater the diffraction.



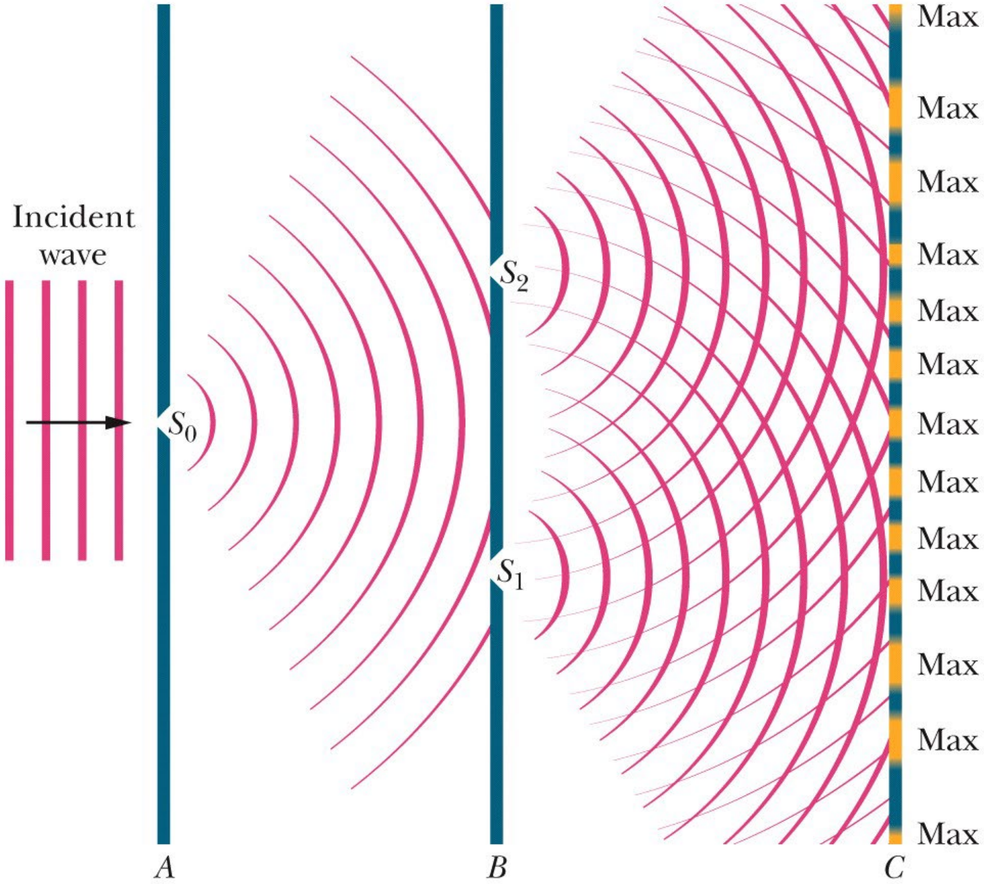


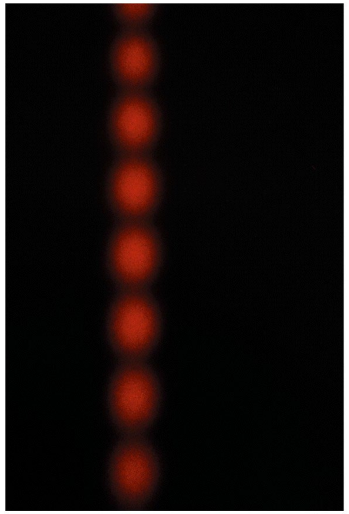
35-2 Young's Interference (5 of 8)

Figure gives the basic arrangement of Young's experiment.

Light from a distant monochromatic source illuminates slit S_0 in screen A. The emerging light then spreads via diffraction to illuminate two slits S_1 and S_2 in screen B.

Diffraction of the light by these two slits sends overlapping circular waves into the region beyond screen B, where the waves from one slit interfere with the waves from the other slit.





Courtesy Jearl Walker

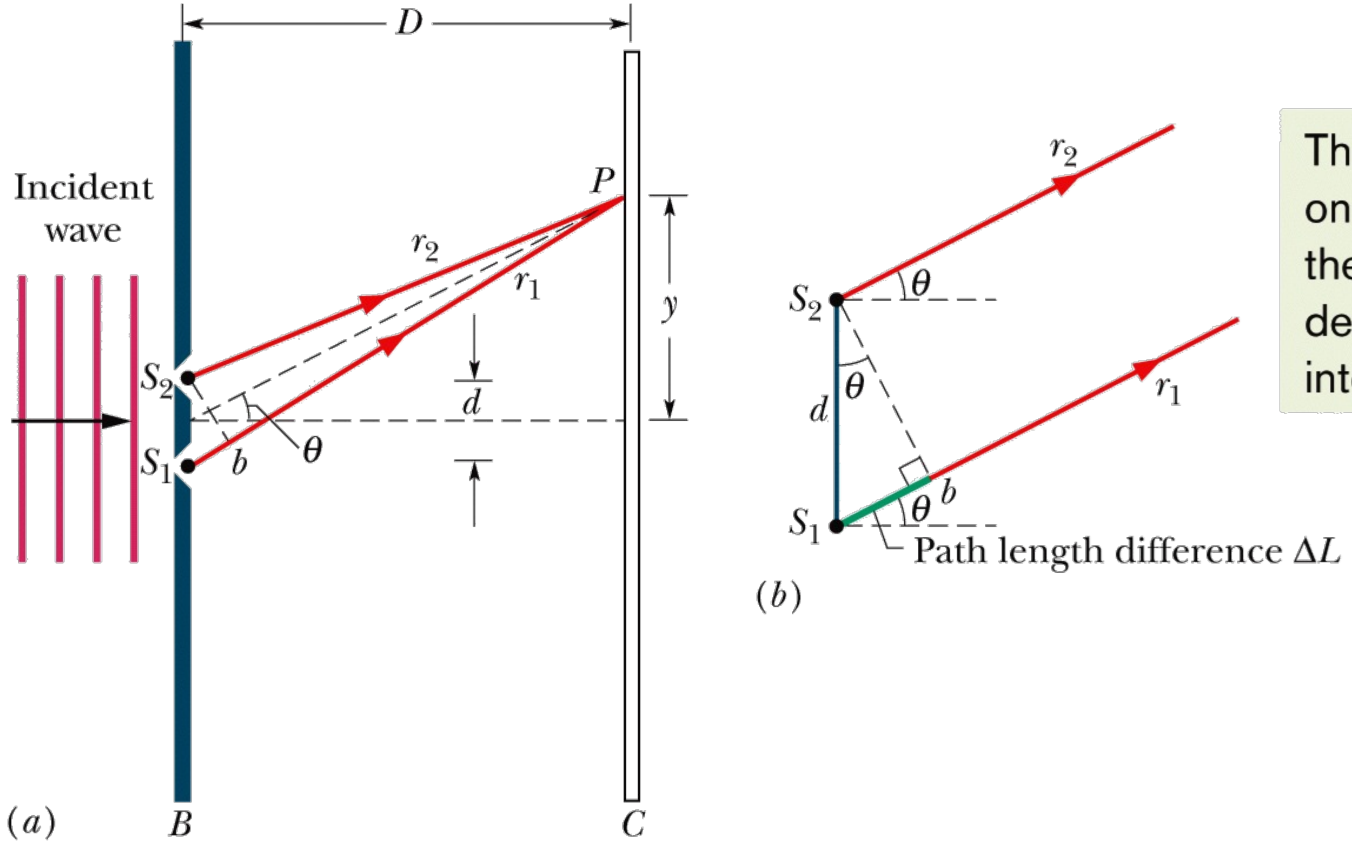
A photograph of the interference pattern produced by the arrangement shown in the figure(right), but with short slits. (The photograph is a front view of part of screen *C* of figure on left.) The alternating maxima and minima are called interference fringes (because they resemble the decorative fringe sometimes used on clothing and rugs).

35-2 Young’s Interference (7 of 8)

(a) Waves from slits S_1 and S_2 (which extend into and out of the page) combine at P, an arbitrary point on screen C at distance y from the central axis. The angle θ serves as a convenient locator for P.

(b) For $D >> d$, we can approximate rays r_1 and r_2 as being parallel, at angle θ to the central axis.

$$\Delta L = d \sin \theta \quad \text{(path length difference)}.$$



The ΔL shifts one wave from the other, which determines the interference.

35-2 Young's Interference (8 of 8)

The phase difference between two waves can change if the waves travel paths of different lengths.

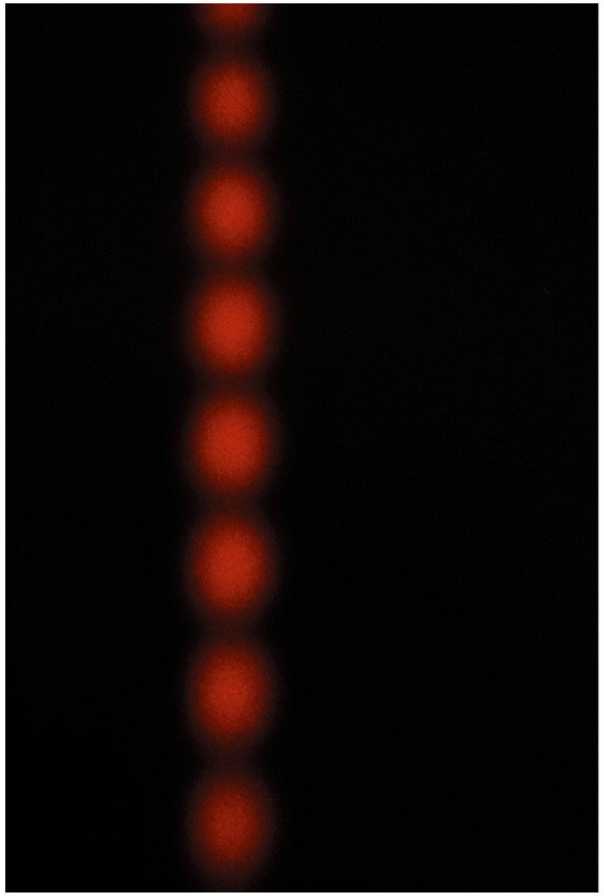
The conditions for maximum and minimum intensity are

For a bright fringe, we saw that ΔL must be either zero or an integer number of wavelengths.

$$\Delta L = d \sin \theta = m\lambda, \quad \text{for } m = 0, 1, 2, \ldots$$

For a dark fringe, ΔL must be an odd multiple of half a wavelength.

$$\Delta L = d \sin \theta = \left(m + \frac{1}{2}\right)\lambda, \quad \text{for } m = 0, 1, 2, \ldots$$



Courtesy Jearl Walker

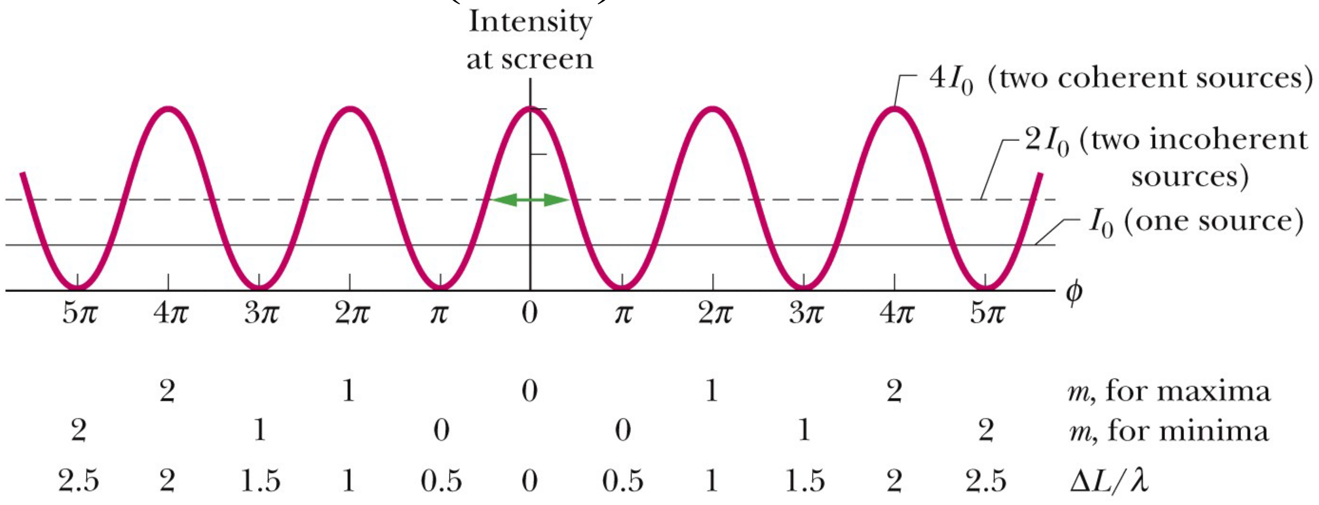
35-3 Interference and Double-Slit Intensity
(3 of 4)

If two light waves that meet at a point are to interfere perceptibly, both must have the same wavelength and the phase difference between them must remain constant with time; that is, the waves must be coherent (相干的).

$$\Delta L = d \sin\theta = m\lambda, \quad \text{for } m = 0, 1, 2, \ldots$$

$$\Delta L = d \sin\theta = \left(m + \frac{1}{2}\right)\lambda, \quad \text{for } m = 0, 1, 2, \ldots$$

A plot of equation below, showing the intensity of a double-slit interference pattern as a function of the phase difference between the waves when they arrive from the two slits. I_0 is the (uniform) intensity that would appear on the screen if one slit were covered. The average intensity of the fringe pattern is $2I_0$, and the maximum intensity (for coherent light) is $4I_0$.



35-3 Interference and Double-Slit Intensity (4 of 4)

As shown in figure, in Young's interference experiment, two waves, each with intensity I_0, yield a resultant wave of intensity I at the viewing screen, with

$$I = 4I_0 \cos^2 \frac{1}{2}\phi,$$

where

$$\phi = \frac{2\pi d}{\lambda} \sin\theta.$$

Maxima $\quad \frac{1}{2}\phi = m\pi, \quad$ for $m = 0, 1, 2, \ldots.$ $\quad$ $(becasue\ d\ \sin\ \theta = m\lambda)$

Minima $\quad \frac{1}{2}\phi = (m + \frac{1}{2})\pi, \quad$ for $m = 0, 1, 2, \ldots.$ $\quad$ (because $d\ \sin\ \theta = \left(m + \frac{1}{2}\right)\lambda$)

35-3 Interference and Double-Slit Intensity (4 of 4)

Three light waves combine at a certain point where their electric field components are

$$E_1 = E_0 \sin \omega t,$$

$$E_2 = E_0 \sin(\omega t + 60°),$$

$$E_3 = E_0 \sin(\omega t - 30°).$$

Find their resultant component $E(t)$ at that point.

35-3 Interference and Double-Slit Intensity (4 of 4)

Three light waves combine at a certain point where their electric field components are

$$E_1 = E_0 \sin \omega t,$$
$$E_2 = E_0 \sin(\omega t + 60°),$$
$$E_3 = E_0 \sin(\omega t - 30°).$$

Find their resultant component $E(t)$ at that point.

$$E(t) = E_1(t) + E_2(t) + E_3(t).$$

choose $t = 0$

Horizontal components

$$\sum E_h = E_0 \cos 0 + E_0 \cos 60° + E_0 \cos(-30°) = 2.37E_0.$$

vertical components

$$\sum E_v = E_0 \sin 0 + E_0 \sin 60° + E_0 \sin(-30°) = 0.366E_0.$$

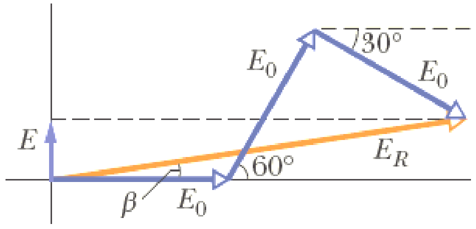


Figure 35-14 Three phasors, representing waves with equal amplitudes E_0 and with phase constants 0°, 60°, and –30°, shown at time $t = 0$. The phasors combine to give a resultant phasor with magnitude E_R, at angle β.

amplitude E_R $\quad E_R = \sqrt{(2.37E_0)^2 + (0.366E_0)^2} = 2.4E_0.$

phase angle β $\quad \beta = \tan^{-1}\left(\frac{0.366E_0}{2.37E_0}\right) = 8.8°$

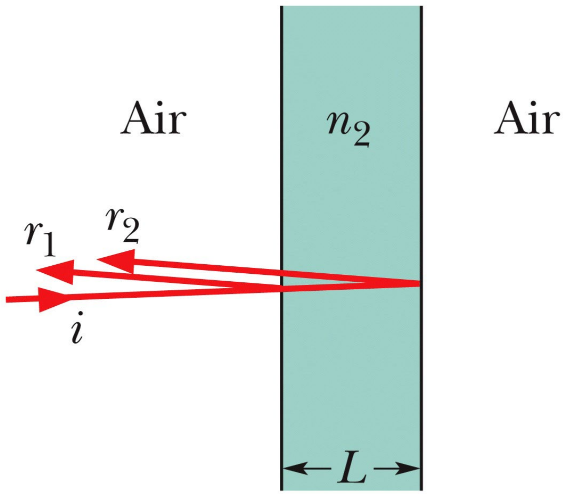
resultant wave $E(t)$

$$E = E_R \sin(\omega t + \beta)$$
$$= 2.4E_0 \sin(\omega t + 8.8°)$$

35-4 Interference from thin films (3 of 7)

When light is incident on a thin transparent film, the light waves reflected from the front and back surfaces interfere.

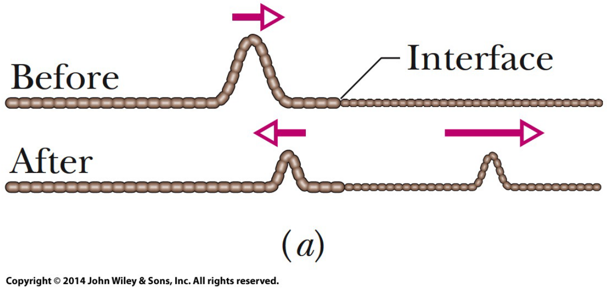
Refraction at an interface never causes a phase change—but reflection can, depending on the indexes of refraction on the two sides of the interface

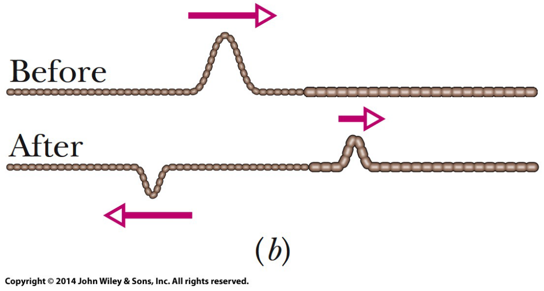


Reflections from a thin film in air.

Reflection	Reflection phase shift
Off lower index	0
Off higher index	0.5 wavelength

35-4 Interference from thin films (7 of 7)





From low speed to high speed (high density to low density)

The incident pulse is in the denser string.

Reflection	Reflection phase shift
Off lower index	0
Off higher index	0.5 wavelength

From high speed to low speed (low density to high density)

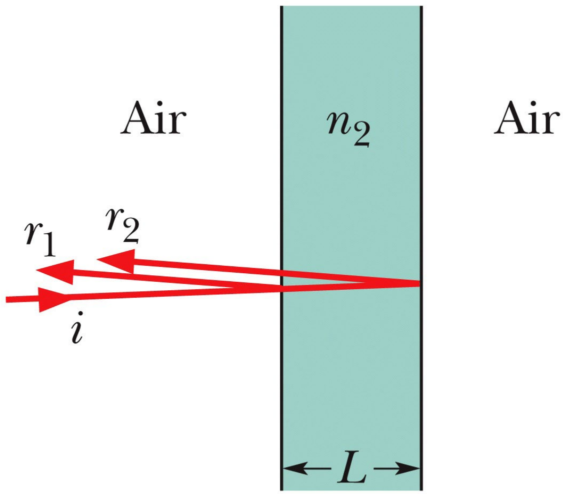
The incident pulse in the lighter string. Only here is there a phase change, and only in the reflected wave.

35-4 Interference from thin films (3 of 7)

Table 35-1 An Organizing Table for Thin-Film Interference in Air (Fig. 35-17)[a]

		r_1	r_2
	Reflection phase shifts	0.5 wavelength	0
	Path length difference	$2L$	
	Index in which path length difference occurs	n_2	
bright film	In phase[a]:	$2L = \frac{\text{odd number}}{2} \times \frac{\lambda}{n_2}$	
dark film	Out of phase[a]:	$2L = \text{integer} \times \frac{\lambda}{n_2}$	

[a]Valid for $n_2 > n_1$ and $n_2 > n_3$.



Reflections from a thin film in air.

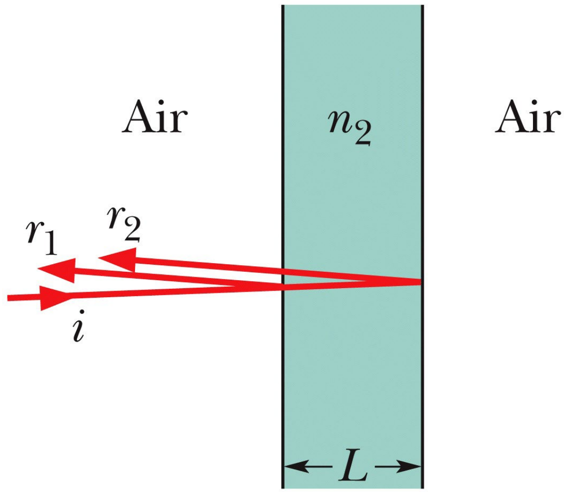
35-4 Interference from thin films (3 of 7)

For near-normal incidence, the wavelength conditions for maximum and minimum intensity of the light reflected from a film with air on both sides are

$$2L = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_2}, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{maxima} - \text{bright film in air}).$$

and

$$2L = m\frac{\lambda}{n_2}, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{maxima} - \text{dark film in air}).$$



Reflections from a thin film in air.

where n_2 is the index of refraction of the film, L is its thickness, and λ is the wavelength of the light in air.

35-4 Interference from thin films (4 of 7)

If a film is sandwiched between media other than air, these equations for bright and dark films may be interchanged, depending on the relative indexes of refraction.

bright film	In phase[a]:	$2L = \frac{\text{odd number}}{2} \times \frac{\lambda}{n_2}$
dark film	Out of phase[a]:	$2L = \text{integer} \times \frac{\lambda}{n_2}$

[a]Valid for $n_2 > n_1$ and $n_2 > n_3$.

35-4 Interference from thin films (4 of 7)

White light, with a uniform intensity across the visible wavelength range of 400 to 690 nm, is perpendicularly incident on a water film, of index of refraction $n_2 = 1.33$ and thickness $L = 320$ nm, that is suspended in air. At what wavelength λ is the light reflected by the film brightest to an observer?

Table 35-1 An Organizing Table for Thin-Film Interference in Air (Fig. 35-17)[a]

		r_1	r_2
	Reflection phase shifts	0.5 wavelength	0
	Path length difference	$2L$	
	Index in which path length difference occurs	n_2	
bright film	In phase[a]:	$2L = \frac{\text{odd number}}{2} \times \frac{\lambda}{n_2}$	
dark film	Out of phase[a]:	$2L = \text{integer} \times \frac{\lambda}{n_2}$	

[a]Valid for $n_2 > n_1$ and $n_2 > n_3$.

35-4 Interference from thin films (4 of 7)

White light, with a uniform intensity across the visible wavelength range of 400 to 690 nm, is perpendicularly incident on a water film, of index of refraction $n_2 = 1.33$ and thickness $L = 320$ nm, that is suspended in air. At what wavelength λ is the light reflected by the film brightest to an observer?

Table 35-1 An Organizing Table for Thin-Film Interference in Air (Fig. 35-17)[a]

		r_1	r_2
	Reflection phase shifts	0.5 wavelength	0
	Path length difference	$2L$	
	Index in which path length difference occurs	n_2	
bright film	In phase[a]:	$2L = \frac{\text{odd number}}{2} \times \frac{\lambda}{n_2}$	
dark film	Out of phase[a]:	$2L = \text{integer} \times \frac{\lambda}{n_2}$	

[a]Valid for $n_2 > n_1$ and $n_2 > n_3$.

$$2L = \frac{\text{odd number}}{2} \times \frac{\lambda}{n_2},$$

which leads to Eq. 35-36:

$$2L = (m + \tfrac{1}{2}) \frac{\lambda}{n_2}.$$

Solving for λ and substituting for L and n_2, we find

$$\lambda = \frac{2n_2L}{m + \frac{1}{2}} = \frac{(2)(1.33)(320 \text{ nm})}{m + \frac{1}{2}} = \frac{851 \text{ nm}}{m + \frac{1}{2}}.$$

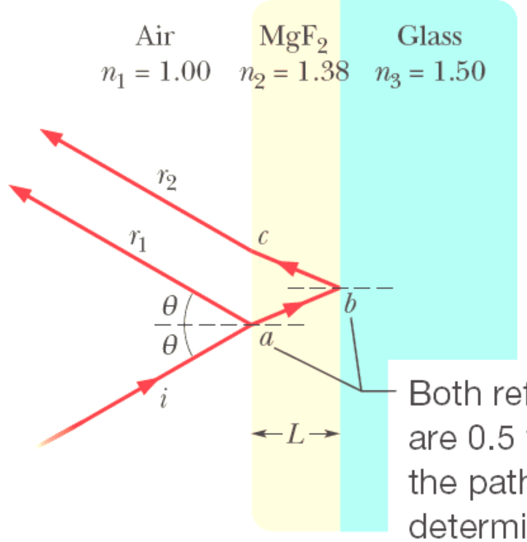
$m = 0$, $\lambda = 1700$ nm, which is in the infrared region.
$m = 1$, $\lambda = 567$ nm, which is yellow-green light, near the middle of the visible spectrum.
$m = 2$, $\lambda = 340$ nm, which is in the ultraviolet region.

observer is brightest is $\lambda = 567$ nm

35-4 Interference from thin films (4 of 7)

In Fig. 35-19, a glass lens is coated on one side with a thin film of magnesium fluoride (MgF_2) to reduce reflection from the lens surface. The index of refraction of MgF_2 is 1.38; that of the glass is 1.50. What is the least coating thickness that 消除 eliminates (via interference) the reflections at the middle of the visible spectrum ($\lambda = 550$ nm)? Assume that the light is approximately perpendicular to the lens surface.

out of phase



Both reflection phase shifts are 0.5 wavelength. So, only the path length difference determines the interference.

If a film is sandwiched between media other than air, these equations for bright and dark films may be interchanged, depending on the relative indexes of refraction.

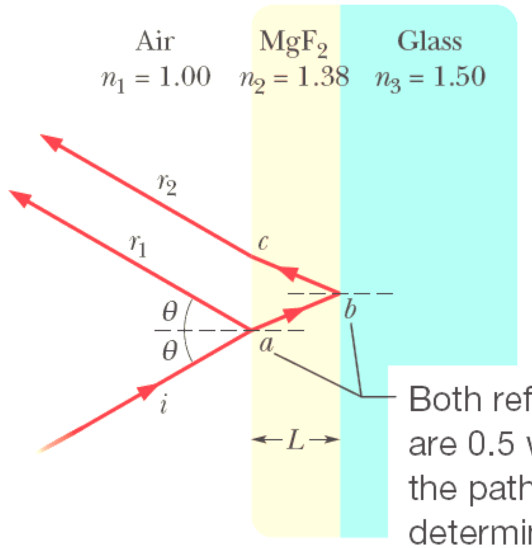
bright film	In phase[a]:	$2L = \frac{\text{odd number}}{2} \times \frac{\lambda}{n_2}$
dark film	Out of phase[a]:	$2L = \text{integer} \times \frac{\lambda}{n_2}$

[a]Valid for $n_2 > n_1$ and $n_2 > n_3$.

35-4 Interference from thin films (4 of 7)

消除

In Fig. 35-19, a glass lens is coated on one side with a thin film of magnesium fluoride (MgF_2) to reduce reflection from the lens surface. The index of refraction of MgF_2 is 1.38; that of the glass is 1.50. What is the least coating thickness that eliminates (via interference) the reflections at the middle of the visible spectrum ($\lambda = 550$ nm)? Assume that the light is approximately perpendicular to the lens surface.



Both reflection phase shifts are 0.5 wavelength. So, only the path length difference determines the interference.

At the first interface, the incident light is in air, which has a lesser index of refraction than the MgF_2. Thus, we fill in 0.5 wavelength under r_1.

At the second interface, the incident light is in the MgF_2, which has a lesser index of refraction than the glass on the other side of the interface. Thus, we fill in 0.5 wavelength under r_2 in our table.

Table 35-1 An Organizing Table for Thin-Film Interference in Air (Fig. 35-17)[a]

	r_1	r_2
Reflection phase shifts	0.5 wavelength	0.5
Path length difference	$2L$	
Index in which path length difference occurs	n_2	
In phase[a]:	$2L = \frac{\text{odd number}}{2} \times \frac{\lambda}{n_2}$	
Out of phase[a]:	$2L = \text{integer} \times \frac{\lambda}{n_2}$	

exchange

[a]Valid for $n_2 > n_1$ and $n_2 > n_3$.

out of phase $\quad 2L = \frac{\text{odd number}}{2} \times \frac{\lambda}{n_2}$

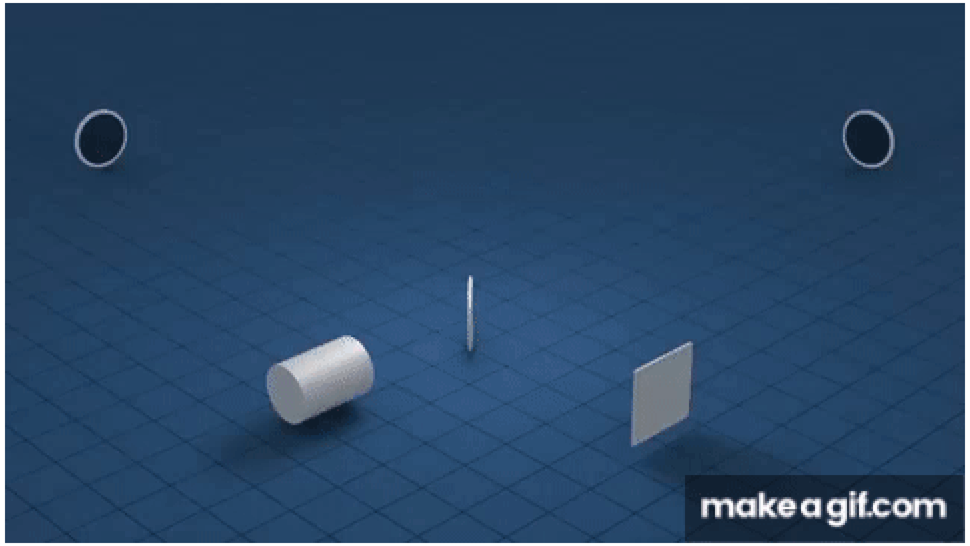
$$L = (m + \tfrac{1}{2})\frac{\lambda}{2n_2}, \qquad \text{for } m = 0, 1, 2, \ldots .$$

the least thickness for the coating, m=0

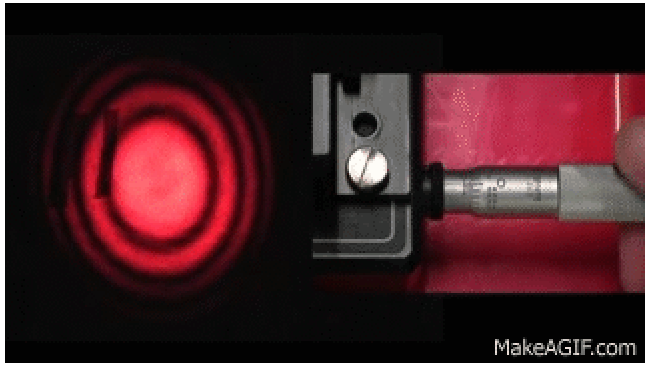
$$L = \frac{\lambda}{4n_2} = \frac{550\text{ nm}}{(4)(1.38)} = 99.6\text{ nm}.$$

35-5 Michelson's Interferometer (迈克逊干涉仪) (2 of 3)

An interferometer is a device that can be used to measure lengths or changes in length with great accuracy by means of interference fringes.



In Michelson's interferometer, **a light wave is split into two beams that then recombine after traveling along different paths.**



The interference pattern they produce depends on the difference in the lengths of those paths and the indexes of refraction along the paths.

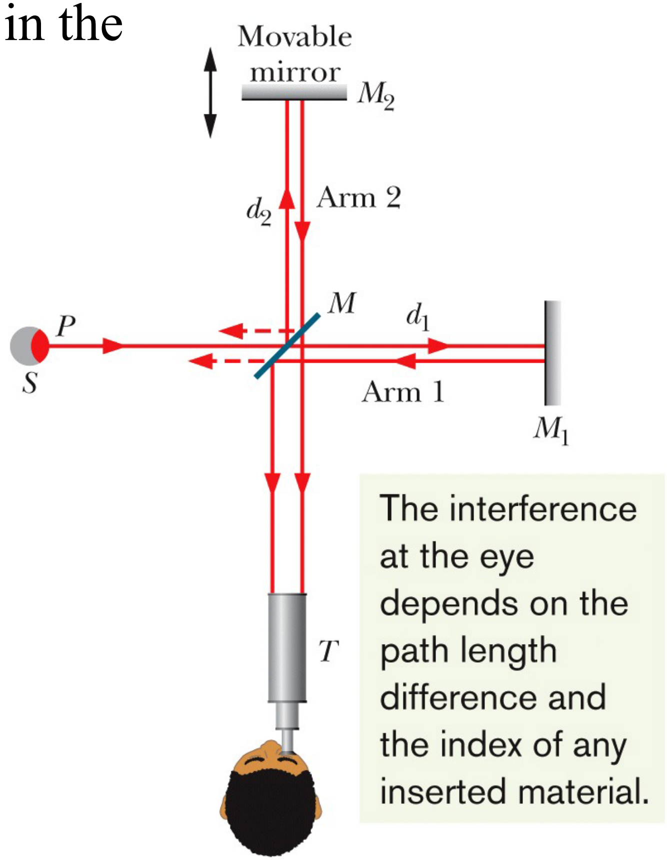
35-5 Michelson's Interferometer (3 of 3)

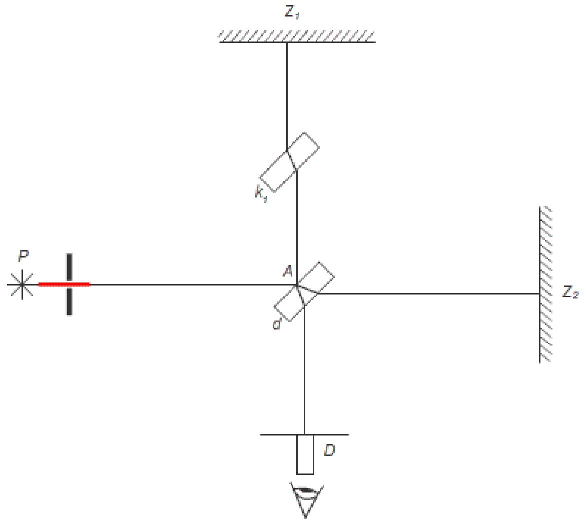
If a transparent material of index n and thickness L is in one path, the phase difference (in terms of wavelength) in the recombining beams is equal to

$$\text{phase difference} = \frac{2L}{\lambda}(n-1),$$

Where λ is the wavelength of the light.

Michelson's interferometer, showing the path of light originating at point P of an extended source S. Mirror M splits the light into two beams, which reflect from mirrors M_1 and M_2 back to M and then to telescope T. In the telescope an observer sees a pattern of interference fringes.





35 Summary (1 of 5)

Huygen’s Principle

- The three-dimensional transmission of waves, including light, may often be predicted by Huygens’ principle, which states that all points on a wavefront serve as point sources of spherical secondary wavelets.

Wavelength and Index of Refraction

- The wavelength λ_n of light in a medium depends on the index of refraction n of the medium:

$$\lambda_n = \frac{\lambda}{n}, \qquad \textbf{Equation (35-6)}$$

in which λ is the wavelength in vacuum.

35 Summary (2 of 5)

Young's Experiment

- In Young's interference experiment, light passing through a single slit falls on two slits in a screen. The light leaving these slits flares out (by diffraction), and interference occurs in the region beyond the screen. A fringe pattern, due to the interference, forms on a viewing screen.
- The conditions for maximum and minimum intensity are

$$d \sin \theta = m\lambda, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{minima} - \text{bright fringes}),$$ **Equation (35-14)**

$$d \sin \theta = \left(m + \frac{1}{2}\right)\lambda, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{minima} - \text{dark fringes}),$$ **Equation (35-16)**

35 Summary (3 of 5)

Coherence

- If two light waves that meet at a point are to interfere perceptibly, both must have the same wavelength and the phase difference between them must remain constant with time; that is, the waves must be coherent.

Intensity in Two-Slit Interference

- In Young's interference experiment, two waves, each with intensity I_0, yield a resultant wave of intensity I at the viewing screen, with

$$I = 4I_0 \cos^2 \frac{1}{2}\phi, \quad \text{where } \phi = \frac{2\pi d}{\lambda} \sin\theta.$$

Equation (35-22 & 23)

35 Summary (4 of 5)

Thin-Film Interference

- When light is incident on a thin transparent film, the light waves reflected from the front and back surfaces interfere. For near-normal incidence, the wavelength conditions for maximum and minimum intensity of the light reflected from a film of index n_2 in air are

$$2L = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_2}, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{maxima} - \text{bright film in air}),$$ **Equation (35-36)**

$$2L = m\frac{\lambda}{n_2}, \quad \text{for } m = 0, 1, 2, \ldots \quad (\text{minima} - \text{dark film in air}),$$ **Equation (35-37)**

35 Summary (5 of 5)

Michelson’s Interferometer

- In Michelson’s interferometer a light wave is split into two beams that, after traversing paths of different lengths, are recombined so they interfere and form a fringe pattern.

34.4.1. Which one of the following statements concerning a convex mirror is true?

a) Such mirrors are always a portion of a large sphere.

b) The image formed by the mirror is sometimes a real image.

c) The image will be larger than one produced by a plane mirror in its place.

d) The image will be closer to the mirror than one produced by a plane mirror in its place.

e) The image will always be inverted relative to the object.

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$$

34.4.1. Which one of the following statements concerning a convex mirror is true?

a) Such mirrors are always a portion of a large sphere.

b) The image formed by the mirror is sometimes a real image.

c) The image will be larger than one produced by a plane mirror in its place.

d) The image will be closer to the mirror than one produced by a plane mirror in its place.

e) The image will always be inverted relative to the object.

34.4.5. Which of the following best describes the type of image formed when an object is placed at a distance greater than the focal point of a concave mirror?

a) real

b) virtual

c) No image is formed in this case.

34.4.5. Which of the following best describes the type of image formed when an object is placed at a distance greater than the focal point of a concave mirror?

a) real

b) virtual

c) No image is formed in this case.

34.5.1. An object is placed at the center of curvature of a concave spherical mirror. Which of the following descriptions best describes the image produced in this situation?

a) upright, larger, real

b) inverted, same size, real

c) upright, larger, virtual

d) inverted, smaller, real

e) inverted, larger, virtual

$$\frac{1}{p}+\frac{1}{i}=\frac{1}{f}=\frac{2}{r},$$

$$f=\frac{1}{2}r$$

34.5.1. An object is placed at the center of curvature of a concave spherical mirror. Which of the following descriptions best describes the image produced in this situation?

a) upright, larger, real

b) inverted, same size, real

c) upright, larger, virtual

d) inverted, smaller, real

e) inverted, larger, virtual

34.8.2. In her biology class, Chris examines an insect wing under a compound microscope that has an objective lens with a focal length of 0.70 cm, an eyepiece with a focal length of 3.0 cm, and a lens separation distance of 16.00 cm. Chris has a near point distance of 22.5 cm. What is the approximate angular magnification of the microscope as Chris views the insect wing?

$$M = m m_\theta = -\frac{s}{f_{ob}}\frac{22.5\ cm}{f_{ey}}$$

a) –75

b) –110

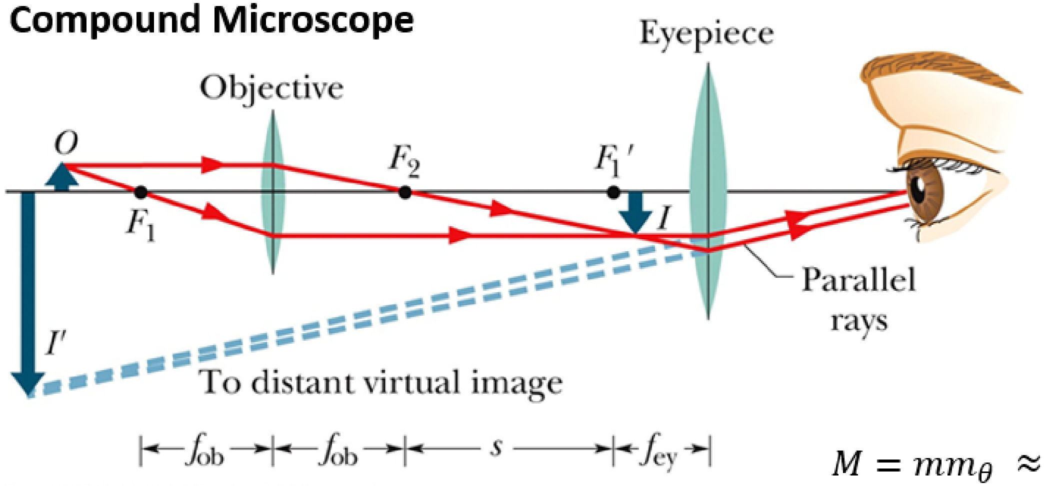
c) –140

d) –160

e) –250

34-5 Optical Instruments (7 of 10)

Compound Microscope



$s \gg f_{ob}$

lateral magnification

$$m = -\frac{i}{p} = \frac{s}{f_{ob}}$$

$$m_\theta \approx \frac{25\ cm}{f_{ey}}$$

$$M = m m_\theta \approx -\frac{s}{f_{ob}}\frac{25\ cm}{f_{ey}}$$

34.8.2. In her biology class, Chris examines an insect wing under a compound microscope that has an objective lens with a focal length of 0.70 cm, an eyepiece with a focal length of 3.0 cm, and a lens separation distance of 16.00 cm. Chris has a near point distance of 22.5 cm. What is the approximate angular magnification of the microscope as Chris views the insect wing?

$$M = m m_\theta = -\frac{s}{f_{ob}}\frac{22.5\ cm}{f_{ey}} = -\frac{16-0.7-3}{0.7}\frac{22.5\ cm}{3\ \mathrm{cm}}$$

a) –75

b) –110

c) –140

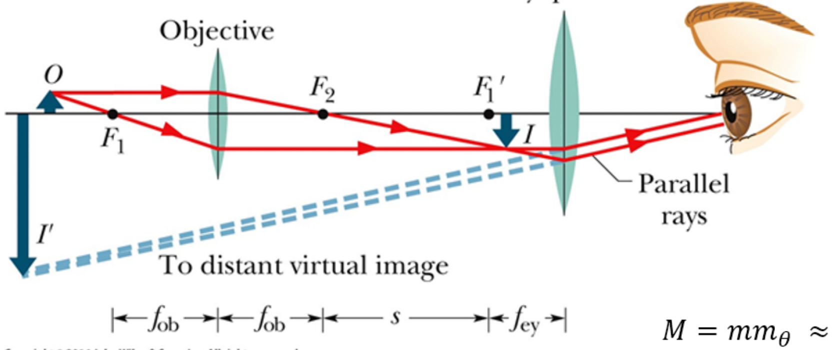
d) –160

e) –250

34-5 Optical Instruments (7 of 10)

$s \gg f_{ob}$

Compound Microscope



lateral magnification

$$m = -\frac{i}{p} = \frac{s}{f_{ob}}$$

$$m_\theta \approx \frac{25\ cm}{f_{ey}}$$

$$M = m m_\theta \approx -\frac{s}{f_{ob}}\frac{25\ cm}{f_{ey}}$$

35.2.2. Blue light travels from air into glass that has an index of refraction of 1.54. How does the wavelength of the light in air compare with the wavelength of the light in the glass?

a) The wavelength of the light is the same in both media, only the frequency changes upon entering the glass.

b) The wavelength of the light becomes shorter in the glass.

c) The wavelength of the light becomes longer in the glass.

35.2.2. Blue light travels from air into glass that has an index of refraction of 1.54. How does the wavelength of the light in air compare with the wavelength of the light in the glass?

a) The wavelength of the light is the same in both media, only the frequency changes upon entering the glass.

b) The wavelength of the light becomes shorter in the glass.

c) The wavelength of the light becomes longer in the glass.

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

35.4.7. A beam of monochromatic light with a wavelength of 660 nm is directed at a double slit. Consider the five fringes labeled in the drawing, including the central maximum that is labeled "B." Which one of these fringes is 330 nm closer to one slit than it is to the other slit?

$$\Delta L = d \sin\theta = m\lambda, \quad \text{for } m = 0, 1, 2, \ldots$$

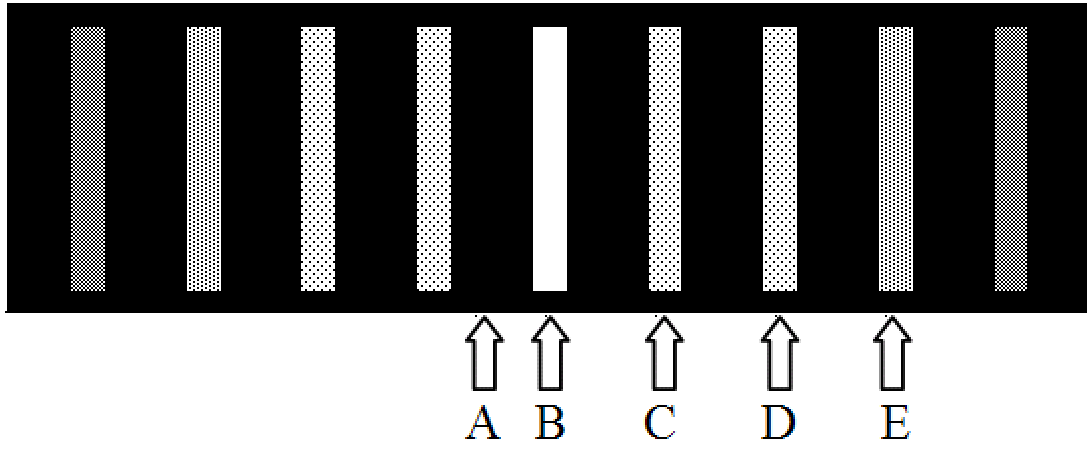
a) A

b) B

c) C

d) D

e) E



35.4.7. A beam of monochromatic light with a wavelength of 660 nm is directed at a double slit. Consider the five fringes labeled in the drawing, including the central maximum that is labeled "B." Which one of these fringes is 330 nm closer to one slit than it is to the other slit?

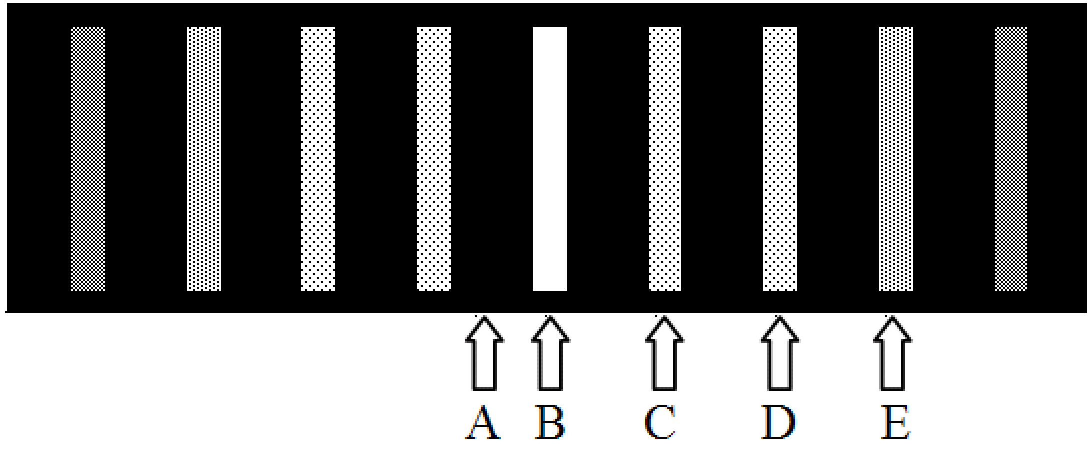
a) A

b) B

c) C

d) D

e) E



35.4.8. A beam of monochromatic light with a wavelength of 660 nm is directed at a double slit. Consider the five fringes labeled in the drawing, including the central maximum that is labeled “B.” Which one of these fringes is produced when the path difference is 1320 nm?

$$\Delta L = d \sin\theta = m\lambda, \quad \text{for } m = 0, 1, 2, \ldots$$

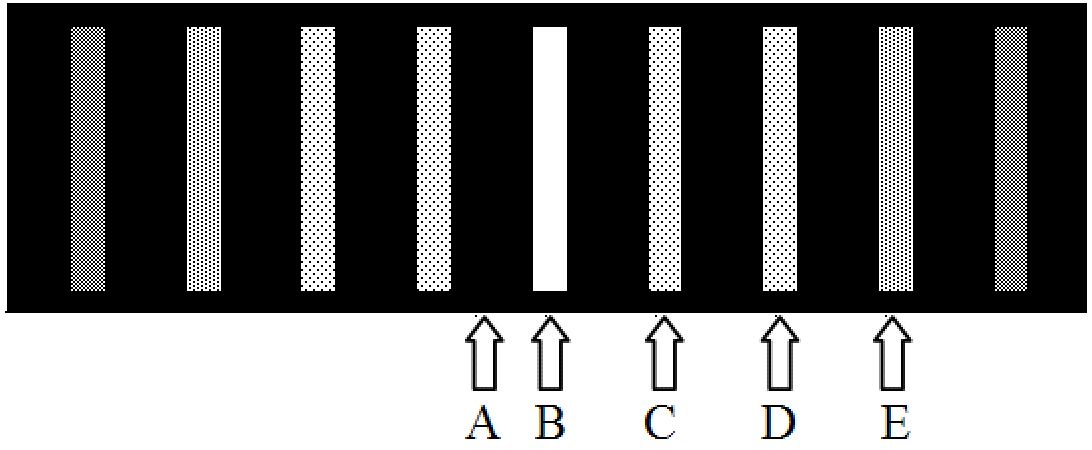
a) A

b) B

c) C

d) D

e) E



35.4.8. A beam of monochromatic light with a wavelength of 660 nm is directed at a double slit. Consider the five fringes labeled in the drawing, including the central maximum that is labeled "B." Which one of these fringes is produced when the path difference is 1320 nm?

a) A

b) B

c) C

d) D

e) E