DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS

IB PHYSICS

LSN 4-4
WAVE BEHAVIOUR

Questions From Reading Activity?

Essential Idea:

- Waves interact with media and each other in a number of ways that can be unexpected and useful.

Nature Of Science:

- Competing theories: The conflicting work of Huygens and Newton on their theories of light and the related debate between Fresnel, Arago and Poisson are demonstrations of two theories that were valid yet flawed and incomplete. This is an historical example of the progress of science that led to the acceptance of the duality of the nature of light.

International-Mindedness:

- Characteristic wave behaviour has been used in many cultures throughout human history, often tying closely to myths and legends that formed the basis for early scientific studies.

Theory Of Knowledge:

- Huygens and Newton proposed two competing theories of the behaviour of light.
- How does the scientific community decide between competing theories?

Understandings:

- Reflection and refraction
- Snell’s law, critical angle and total internal reflection
- Diffraction through a single-slit and around objects
- Interference patterns
- Double-slit interference
- Path difference

Applications And Skills:

- Sketching and interpreting incident, reflected and transmitted waves at boundaries between media
- Solving problems involving reflection at a plane interface

Applications And Skills:

- Solving problems involving Snell's law, critical angle and total internal reflection
- Determining refractive index experimentally

Applications And Skills:

- Qualitatively describing the diffraction pattern formed when plane waves are incident normally on a single-slit
- Quantitatively describing double-slit interference intensity patterns

Guidance:

- Quantitative descriptions of refractive index are limited to light rays passing between two or more transparent media. If more than two media, only parallel interfaces will be considered
- Students will not be expected to derive the double-slit equation
- Students should have the opportunity to observe diffraction and interference patterns arising from more than one type of wave

Data Booklet Reference:

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

$$s = \frac{\lambda D}{d}$$

Data Booklet Reference:

- Constructive Interference: path difference =

$$n\lambda$$

- Destructive Interference: path difference =

$$\left(n+\frac{1}{2}\right)\lambda$$

Utilization:

- A satellite footprint on Earth is governed by the diffraction at the dish on the satellite
- Applications of the refraction and reflection of light range from the simple plane mirror through the medical endoscope and beyond. Many of these applications have enabled us to improve and extend our sense of vision

Utilization:

- The simple idea of the cancellation of two coherent light rays reflecting from two surfaces leads to data storage in compact discs and their successors
- The physical explanation of the rainbow involves refraction and total internal reflection. The bright and dark bands inside the rainbow, supernumeraries, can be explained only by the wave nature of light and diffraction

Aims:

- Aim 1: the historical aspects of this topic are still relevant science and provide valuable insight into the work of earlier scientists
- Aim 8: the increasing use of digital data and its storage density has implications on individual privacy through the permanence of a digital footprint

Aims:

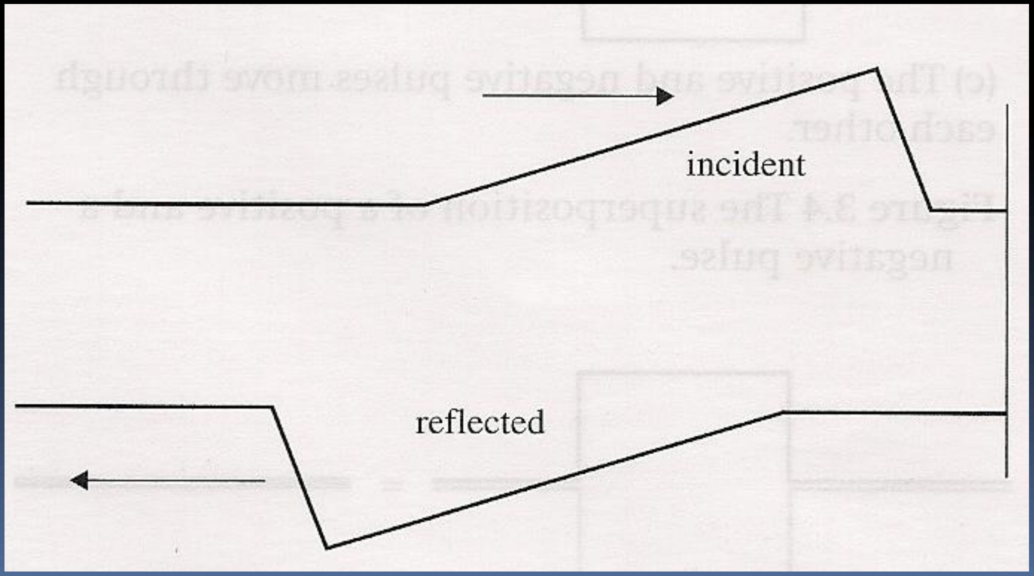
- Aim 6: experiments could include (but are not limited to): determination of refractive index and application of Snell’s law; determining conditions under which total internal reflection may occur; examination of diffraction patterns through apertures and around obstacles; investigation of the double-slit experiment

Law of Reflection

- ***What happens to a pulse on a rope tied to a wall?***

Law of Reflection

- ***What happens to a pulse on a rope tied to a wall?***
- ***The pulse reflects inverted and traveling in the opposite direction:***



Law of Reflection

- ***Law of Reflection***: The ***angle of incidence, i*** (angle between the ray and the normal to the reflecting surface at the point of incidence) is equal to the ***angle of reflection, r*** (angle between the normal and the reflected ray).

Law of Reflection

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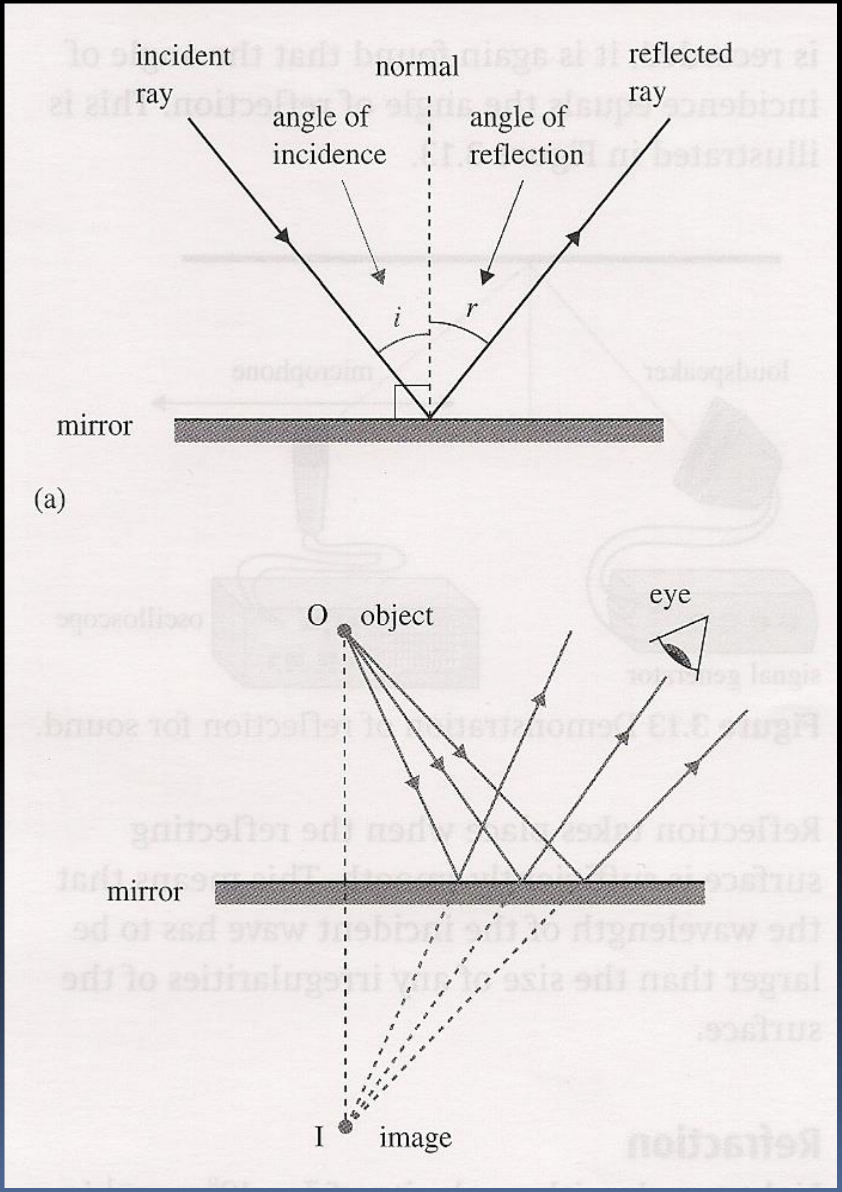
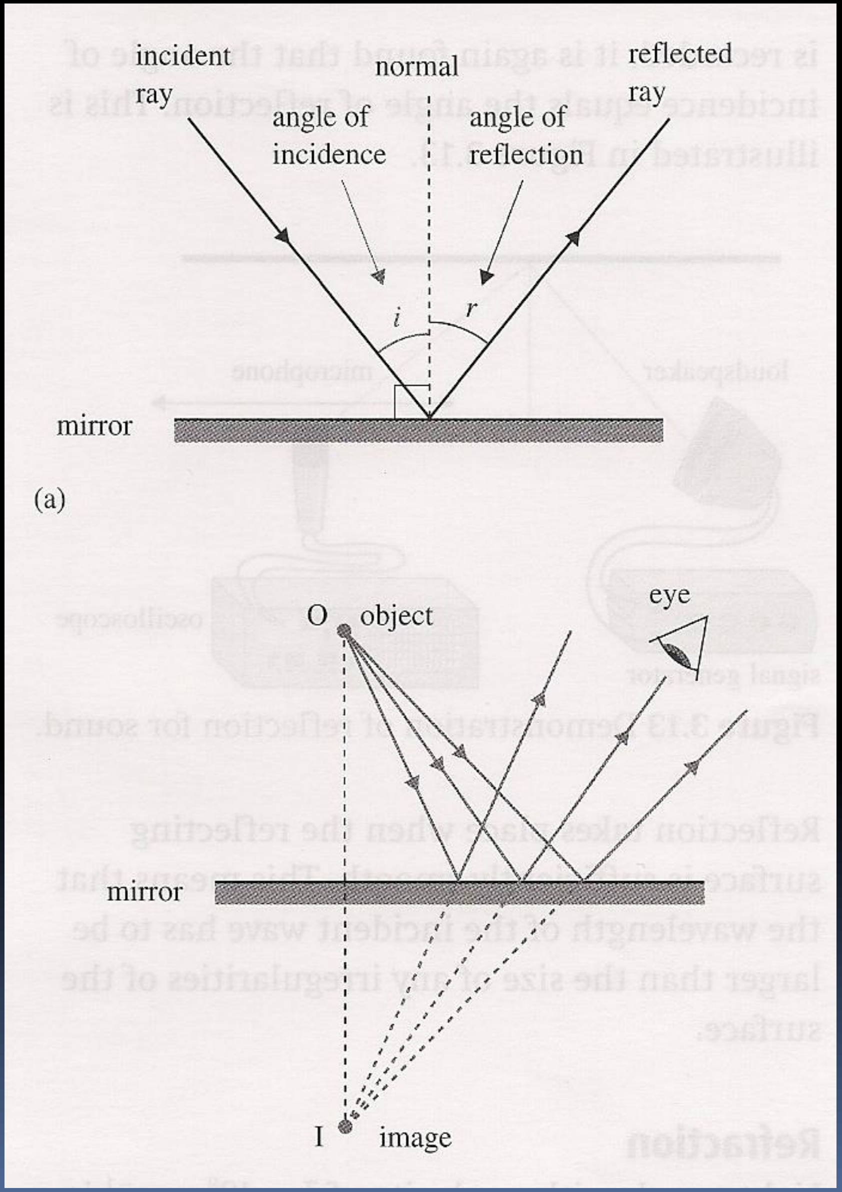


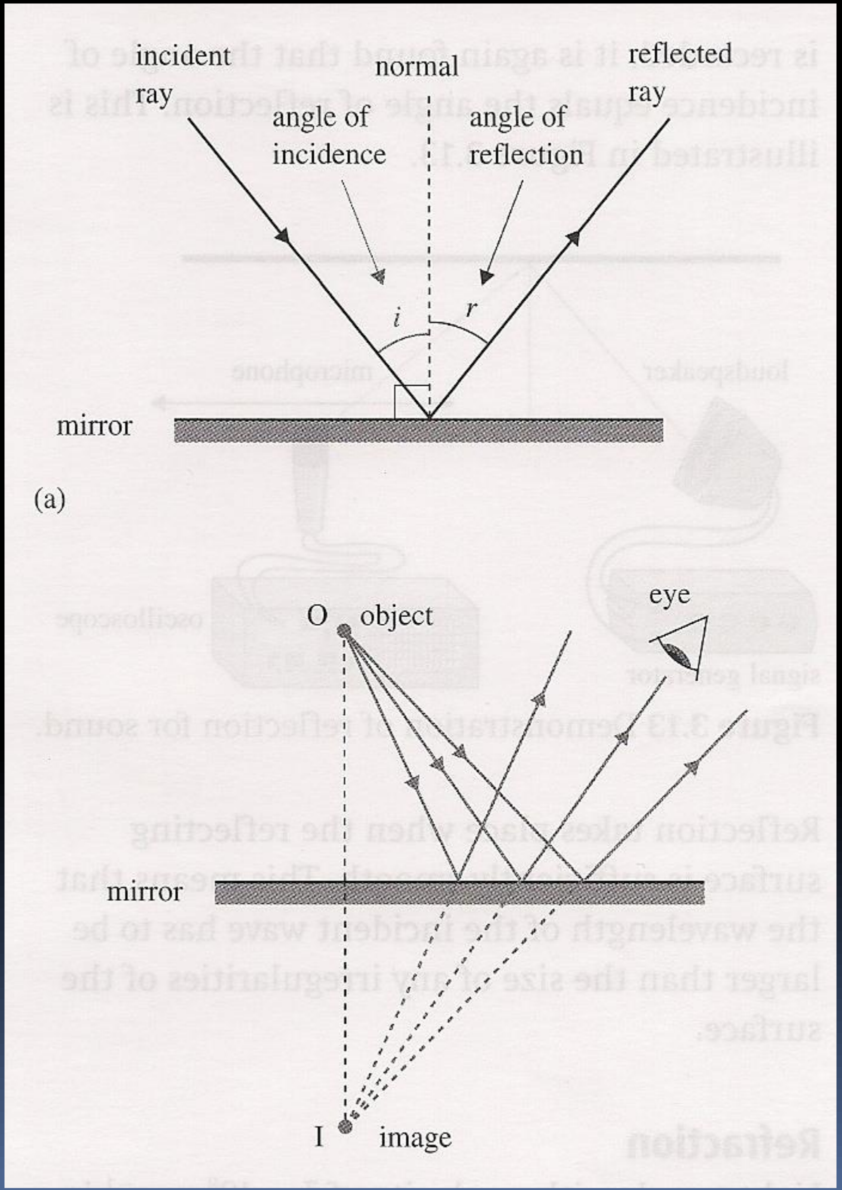
Law of Reflection

- **The reflected and incident rays and the normal to the surface lie on the same plane, called the plane of incidence.**

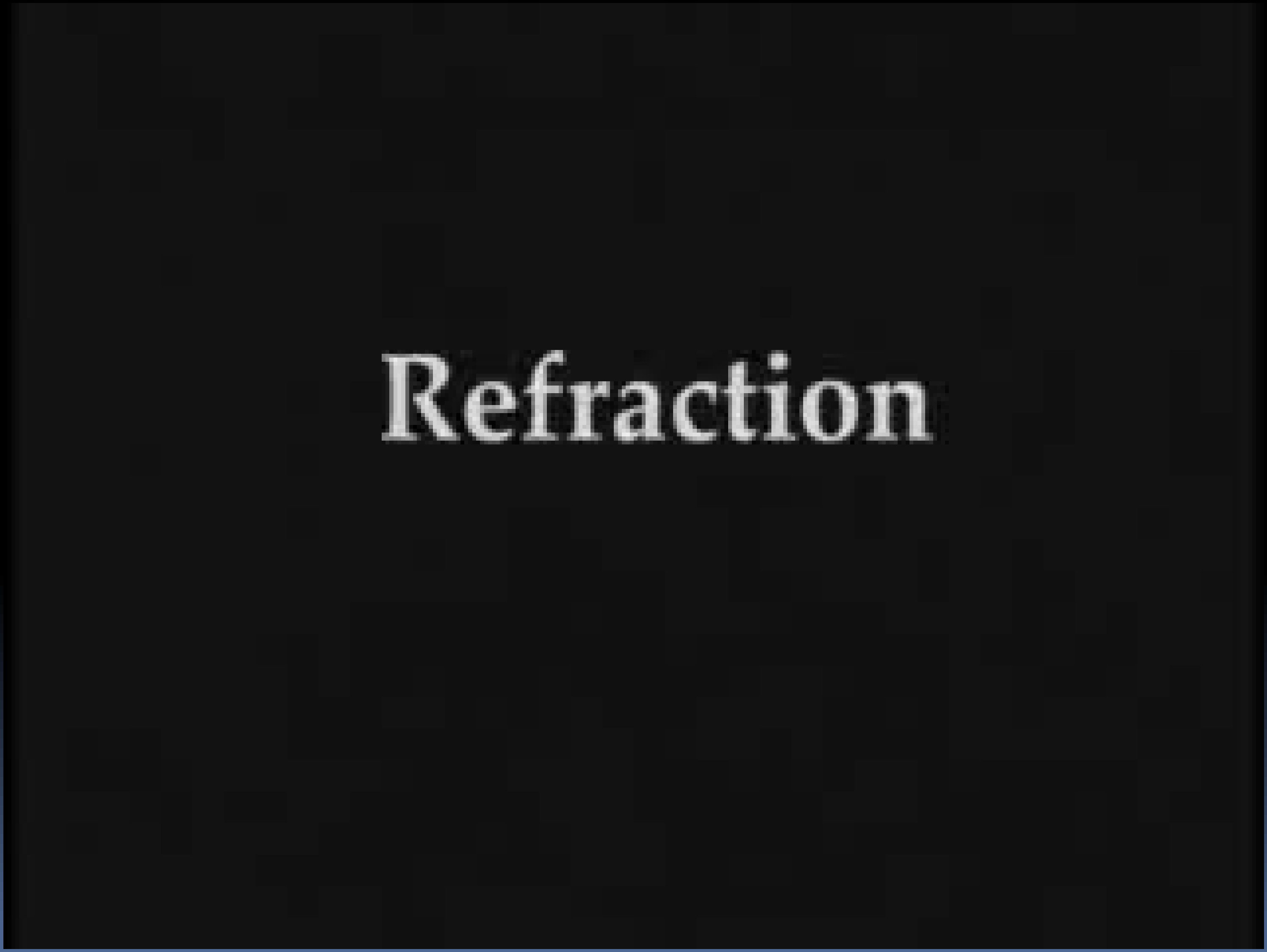


Law of Reflection

- **Reflection takes place when the reflecting surface is sufficiently smooth i.e., the wavelength of the incident wave is larger than any irregularities in the surface**



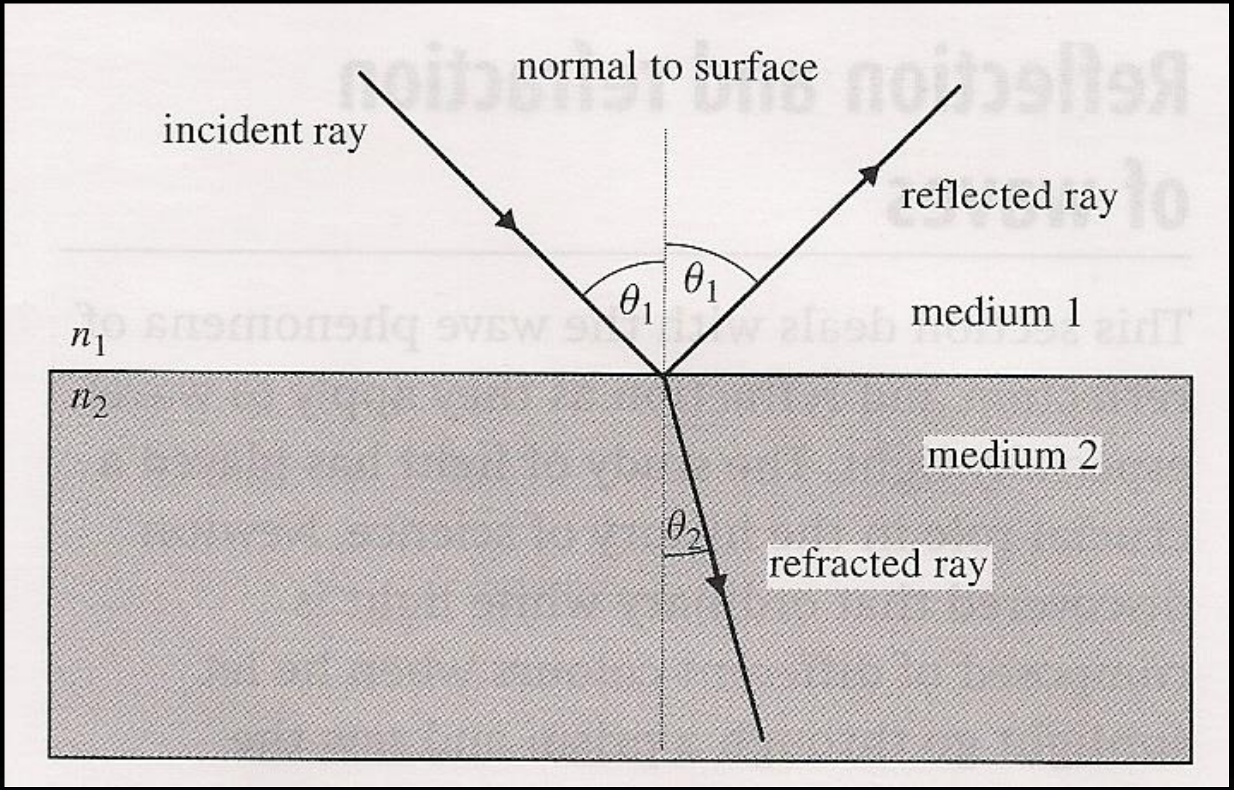
Refraction



Refraction

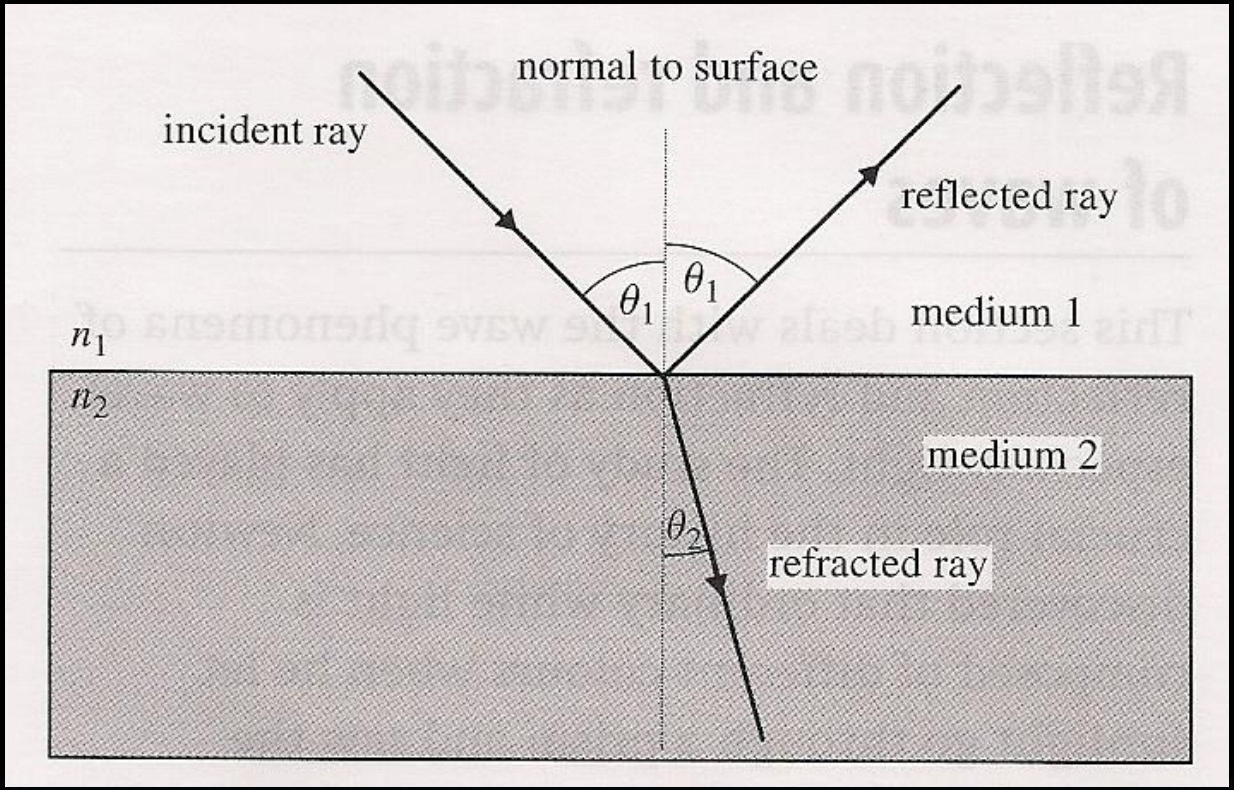
- Light travels fastest in vacuum (3×10^8 m/s)
- It is slower in all other media
- The difference in speed is responsible for the phenomenon of *refraction*

Refraction



- When a ray of light strikes an interface between two media, there is both reflection and refraction

Refraction



- When light travels from a medium of lower density to a medium of higher density, it slows down

Index of Refraction – <u>Light Only</u>

- In the case of light only we define an ***<u>index of refraction</u>*** as:

$$n = \frac{v}{v_m}$$

  - n = index of refraction
  - c = speed of light in a vacuum
  - c_m = speed of light in the given medium
- Since the speed of light is always greatest in a vacuum, the index will always be greater than 1

Index of Refraction – <u>Light Only</u>

- By definition, the index of refraction for a vacuum is equal to 1
- Index of refraction of water is 1.33
- Snell's Law then can be re-written specifically for light:

Snell's Law:

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

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

- θ_1 is the angle between the incident ray and the normal to the surface
- c_1 is the speed of light in the first medium
- θ_2 is the angle between the refracted ray and the normal to the surface
- c_2 is the speed of light in the second medium

Snell's Law:

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

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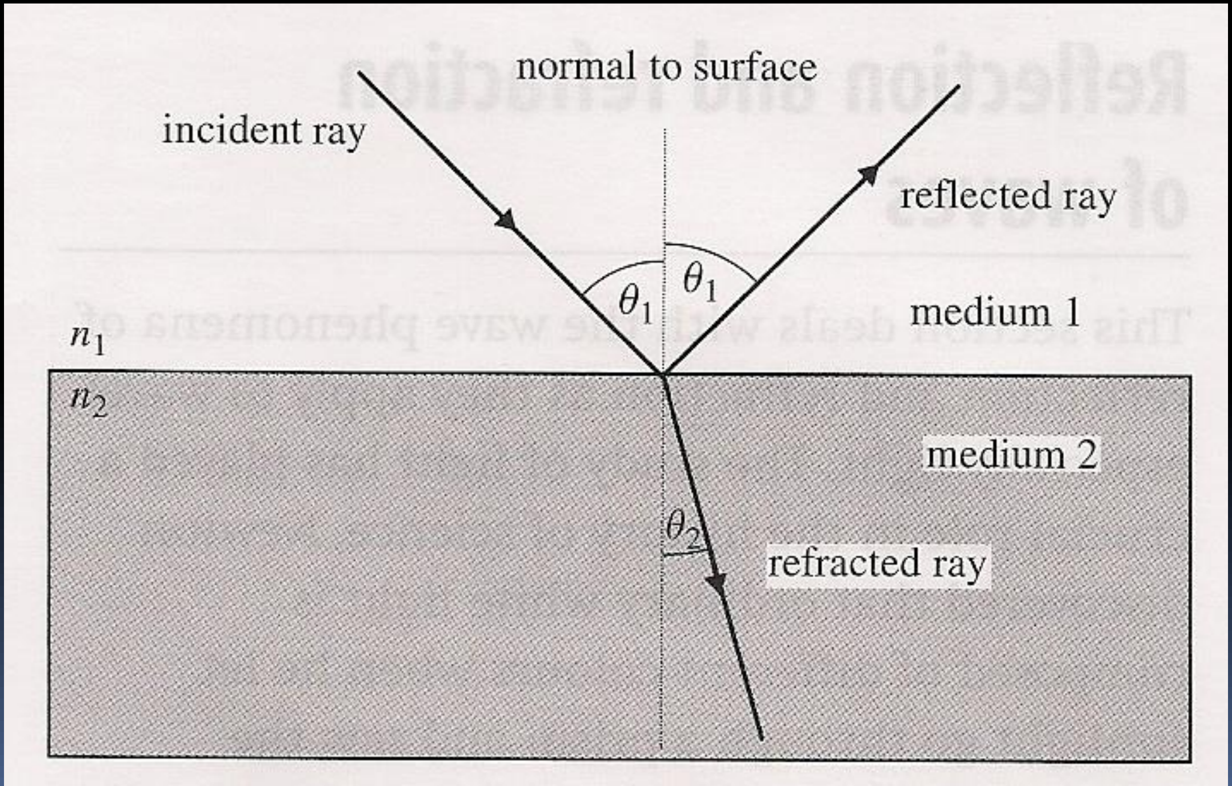


Other Changes

- Velocity changes with a change in media
- But wavelength does change
- Frequency DOES NOT change

An Example:

- ***Light of wavelength 700 nm enters water at an angle of incidence of 45 degrees. Find (a) the angle of refraction and (b) the wavelength of the light in water.***

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

$$(1)\sin(45) = (1.33)\sin\theta_2$$

$$\sin\theta_2 = 0.5317$$

$$\theta_2 = 32.1$$

$$\lambda = 700nm$$

$$f = \frac{v}{\lambda} = \frac{3x10^8}{700x10^{-9}}$$

$$f = 4.29x10^{14}Hz$$

An Example:

- *Light of wavelength 700 nm enters water at an angle of incidence of 45 degrees. Find (a) the angle of refraction and (b) the wavelength of the light in water.*

$$n = \frac{v}{v_m}$$

$$v_m = \frac{v}{n} = \frac{3x10^8}{1.33}$$

$$v_m = 2.26x10^8$$

$$f = \frac{v_m}{\lambda}$$

$$\lambda = \frac{v_m}{f} = \frac{2.26x10^8}{4.29x10^{14}}$$

$$\lambda = 526nm$$

An Example:

- ***Light of wavelength 700 nm enters water at an angle of incidence of 45 degrees. Find (a) the angle of refraction and (b) the wavelength of the light in water.***

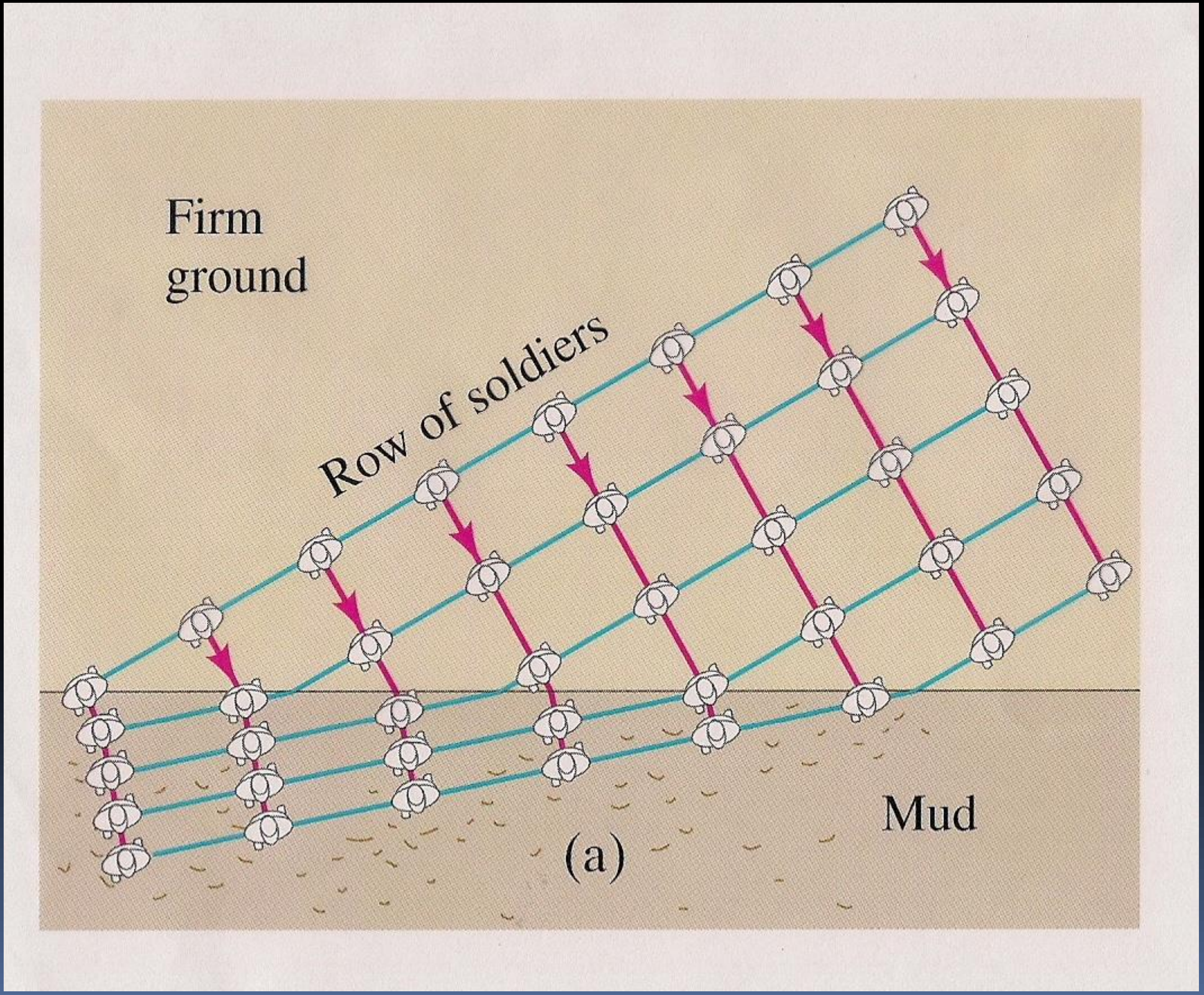
$$v = 3.00x10^{8}\ m/s$$

$$v_m = 2.26x10^{8}\ m/s$$

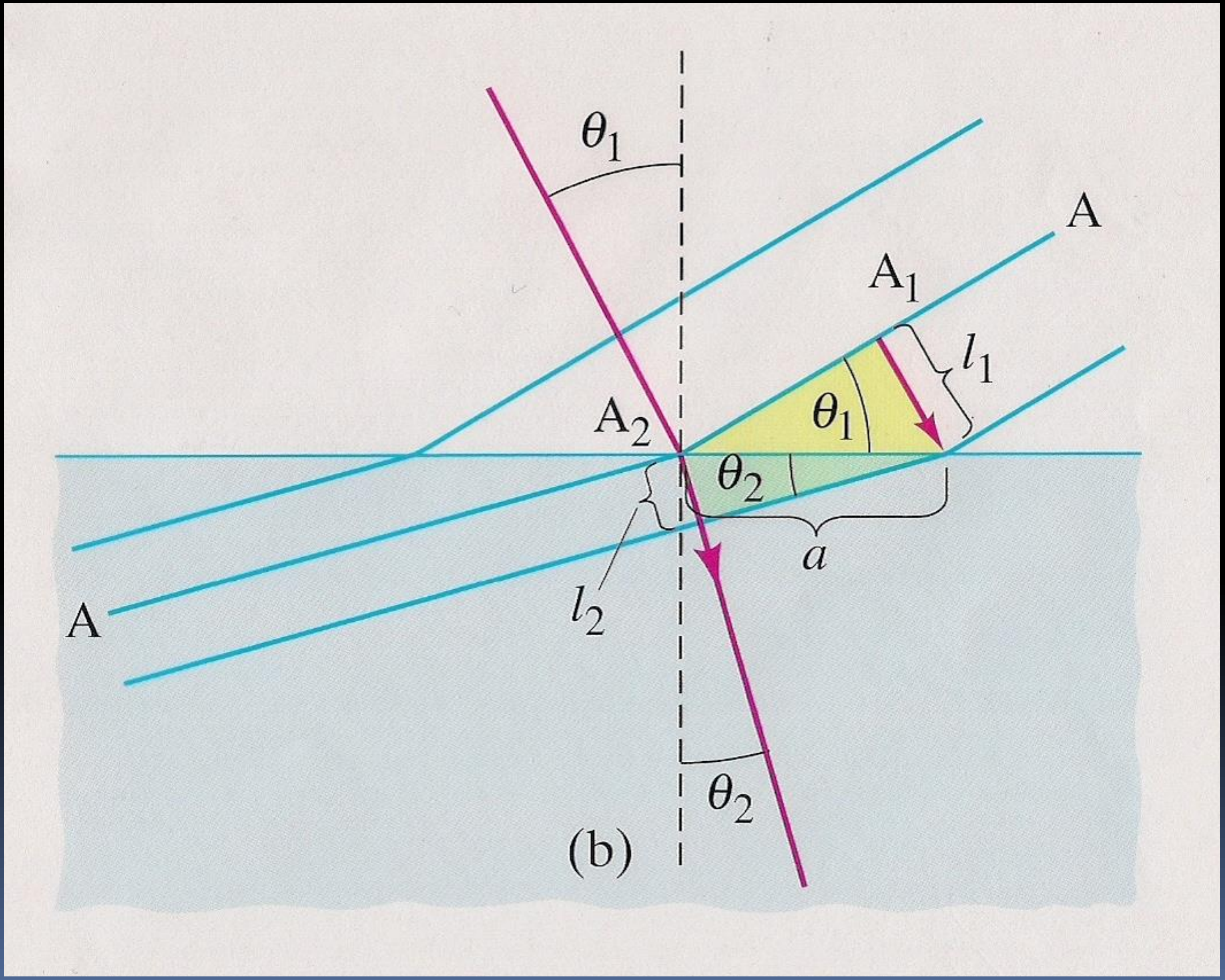
$$\lambda = 700nm$$

$$\lambda_m = 526nm$$

Refraction for Waves versus Rays



Refraction for Waves versus Rays



Refraction for other waves:

- Refraction applies to all waves whenever the wave changes speed when going from one medium to another
- Due to differences in density, sound waves are slowest in air, faster in a liquid, and fastest in a solid.

Refraction for other waves:

Medium	Speed/m s^{-1}
Air (0 °C)	331
Air (100 °C)	366
Helium (0 °C)	972
Oxygen (0 °C)	332
Water	1480
Sea water	1530
Mercury	1454
Aluminium	5100

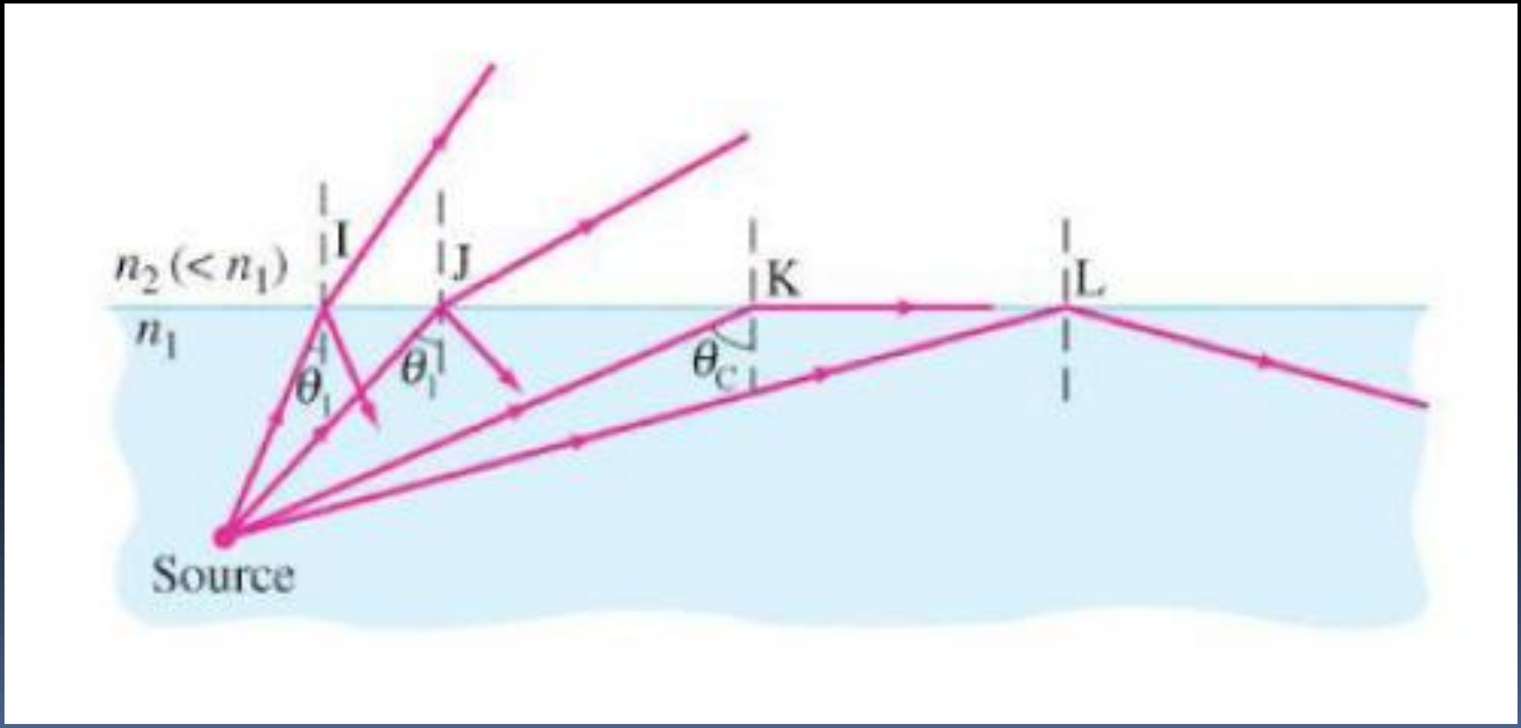
Table 3.1 The speed of sound in various media.

Total Internal Reflection

- When moving from a less dense medium to a medium of higher density, the light refracts ***toward*** the normal line
- When moving from a medium of higher density to a less dense medium, the light refracts ***away from*** the normal line
- As you increase the angle of incidence, the refracted ray approaches being parallel to the surface boundary

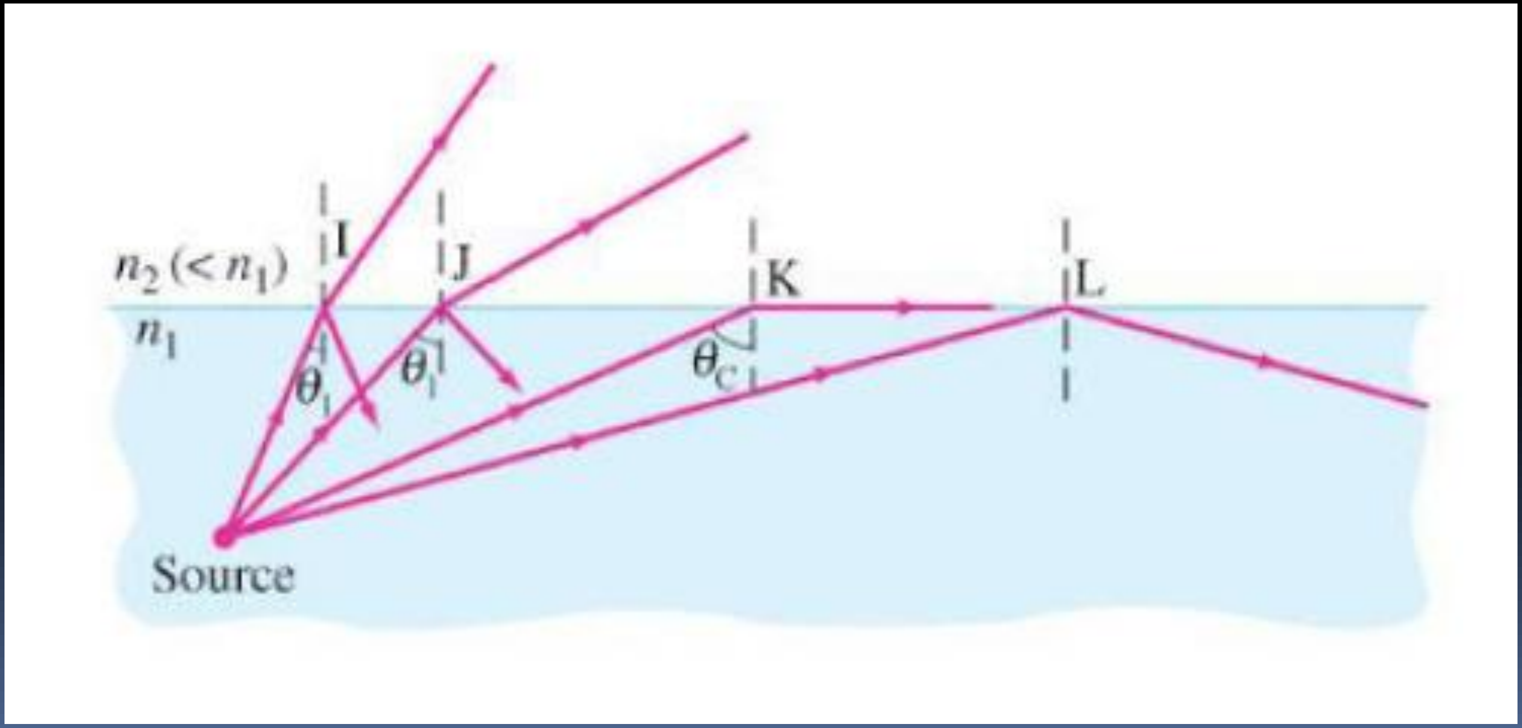
Total Internal Reflection

- At the ***critical angle*** of incidence, the light is completely reflected and none is refracted



Total Internal Reflection

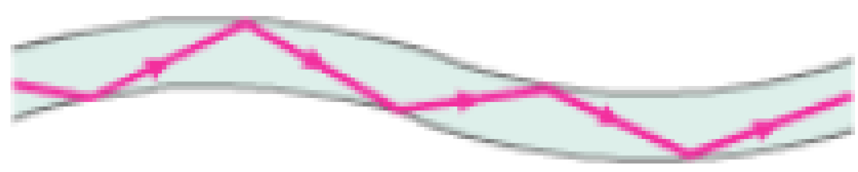
- The critical angle can be found using Snell's Law and using 90° for the refracted angle



Total Internal Reflection

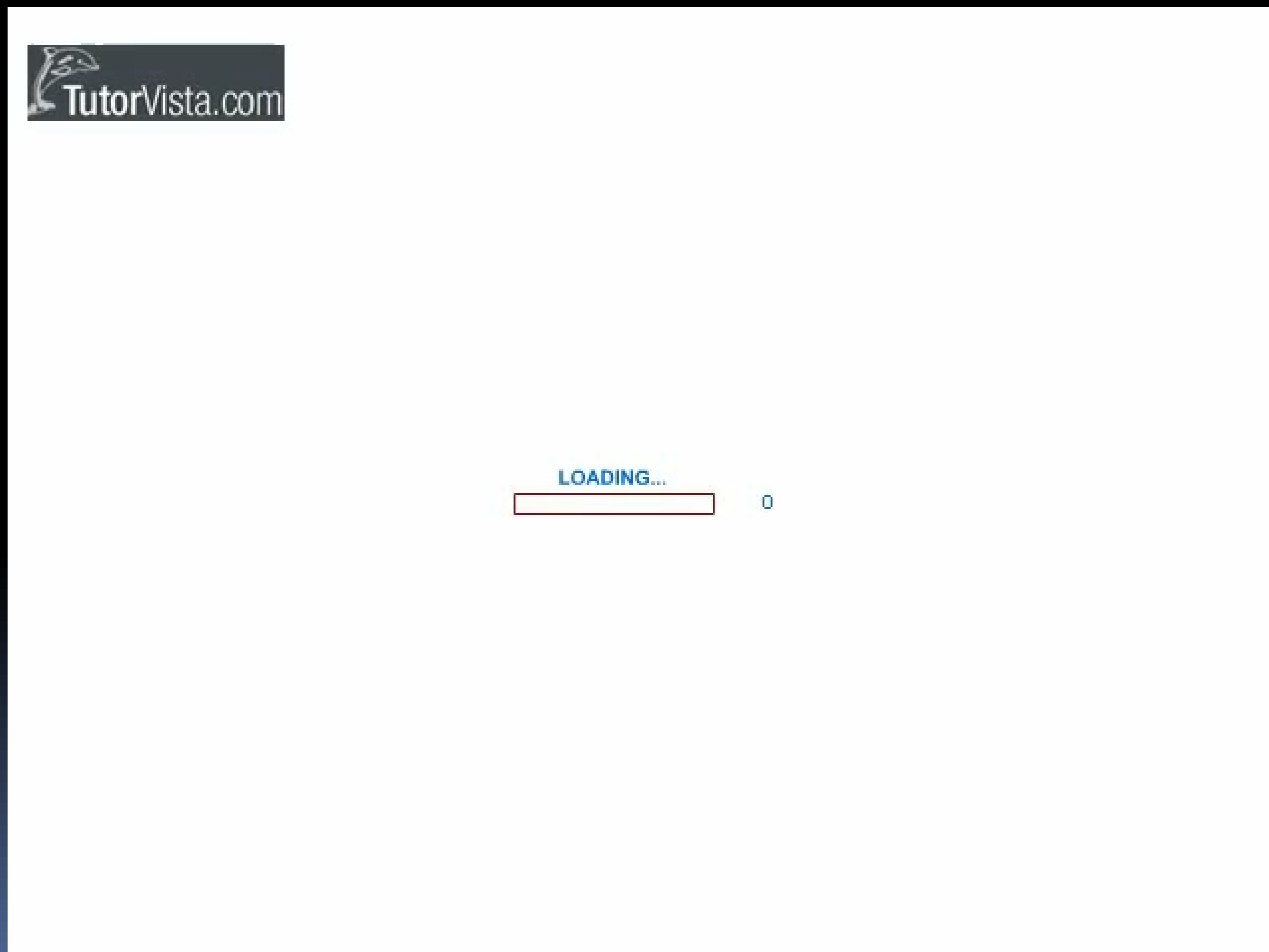
- Total internal reflection is the principle used in fiber optic cables – allows for data speeds at the speed of light (in the given medium)

FIGURE 23–27 Light reflected totally at the interior surface of a glass or transparent plastic fiber.



DIFFRACTION

Diffraction of Light

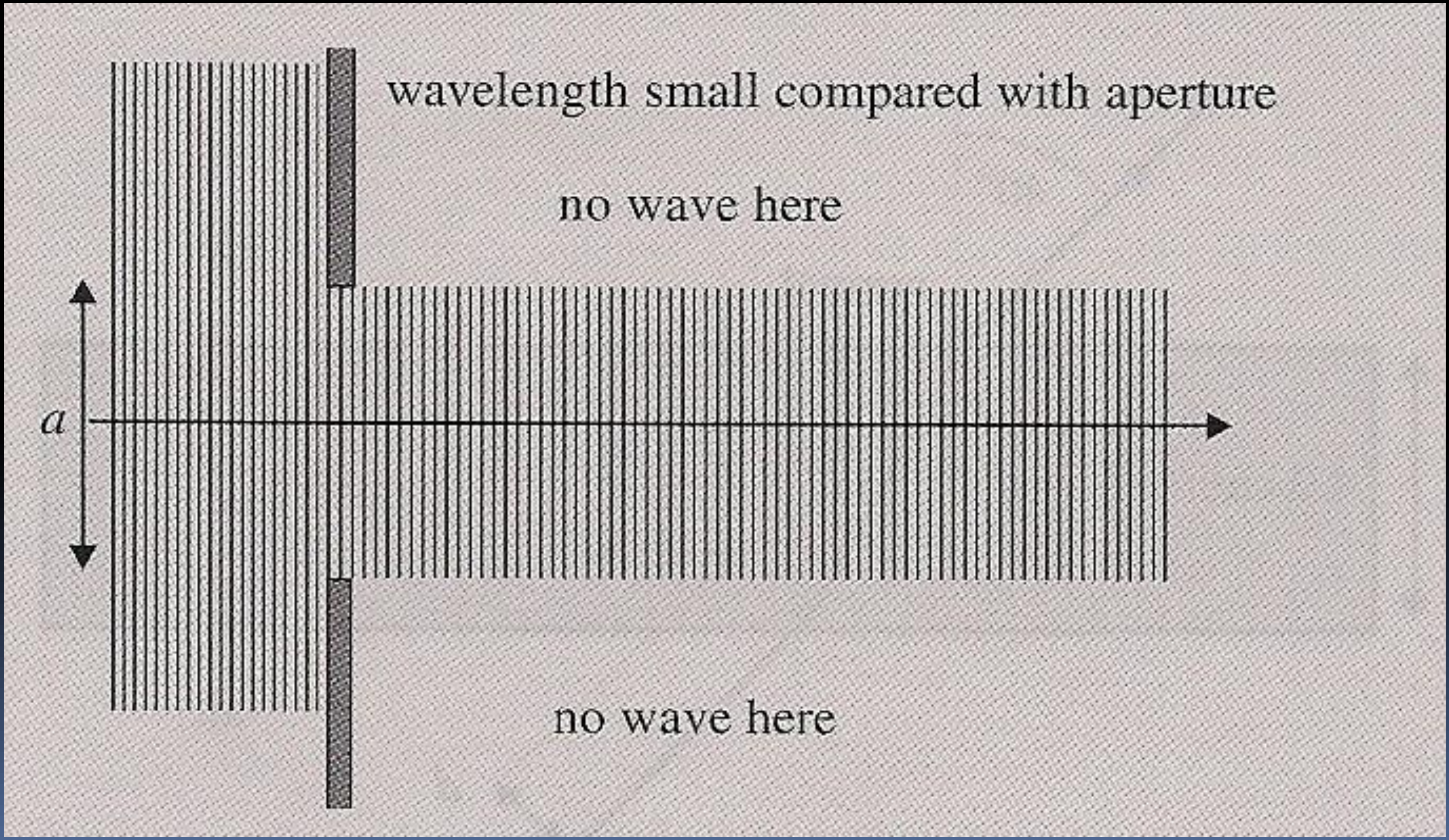


Diffraction:

- The spreading of a wave as it goes past an obstacle or through an aperture
  - Dependent on the value of the wavelength, λ, in relation to the size of the aperture, a

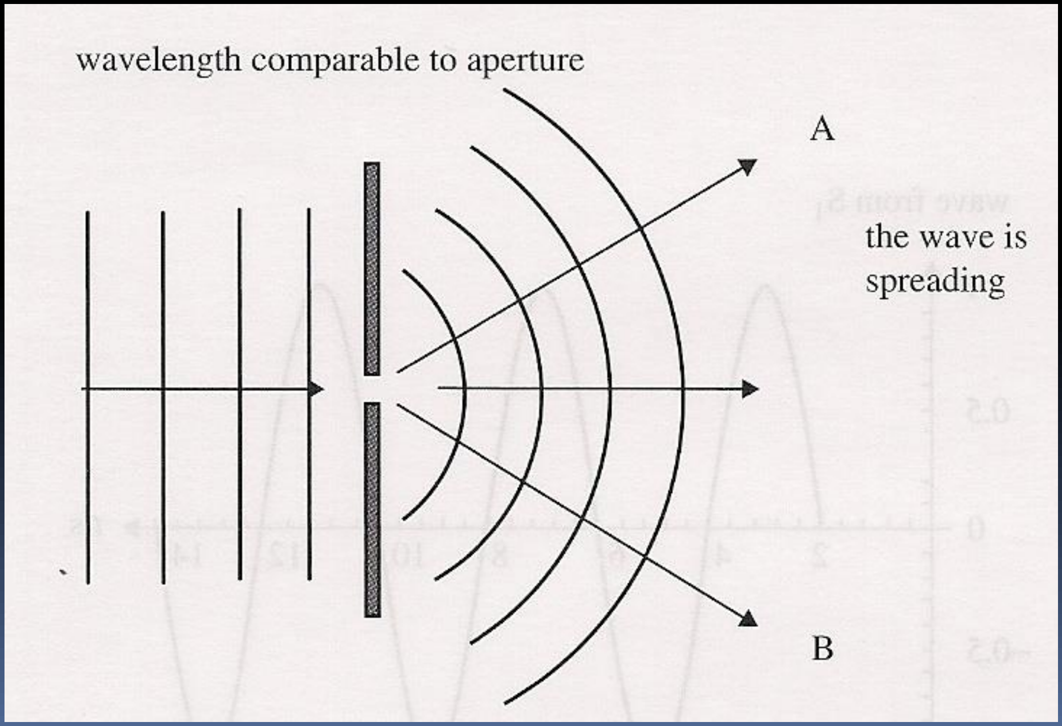
Diffraction:

- **When the wavelength is small compared to the aperture, little or no diffraction occurs**



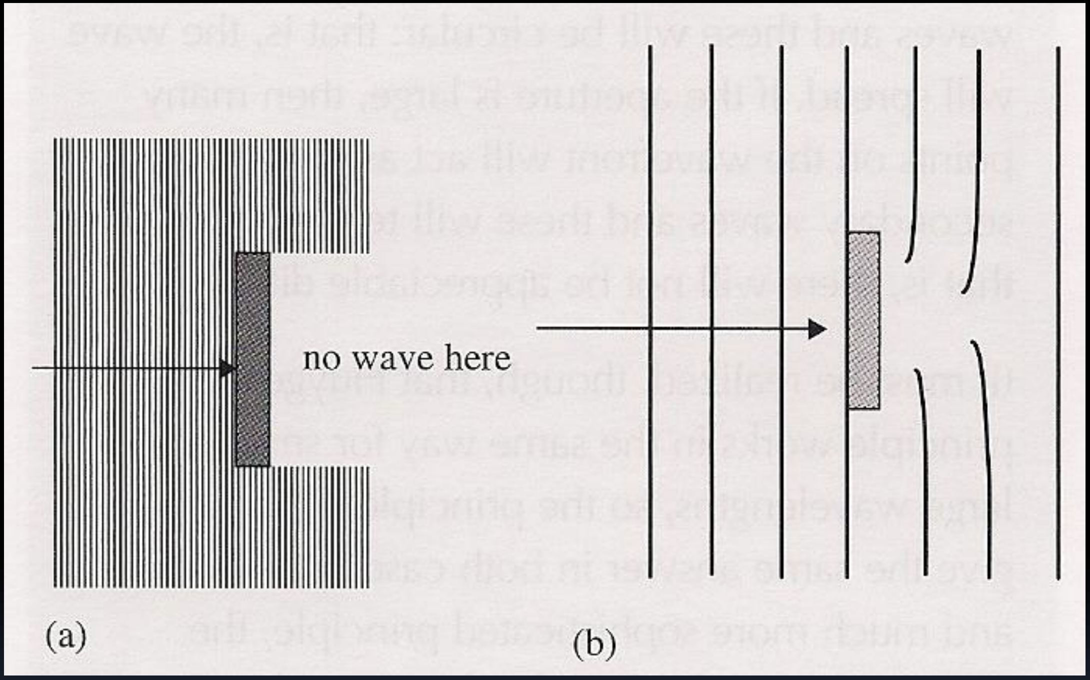
Diffraction:

- If the wavelength, λ, is comparable to or larger than the aperture, a, the wavefronts on the other side of the aperture are curved and the wave spreads out around the edges of the opening



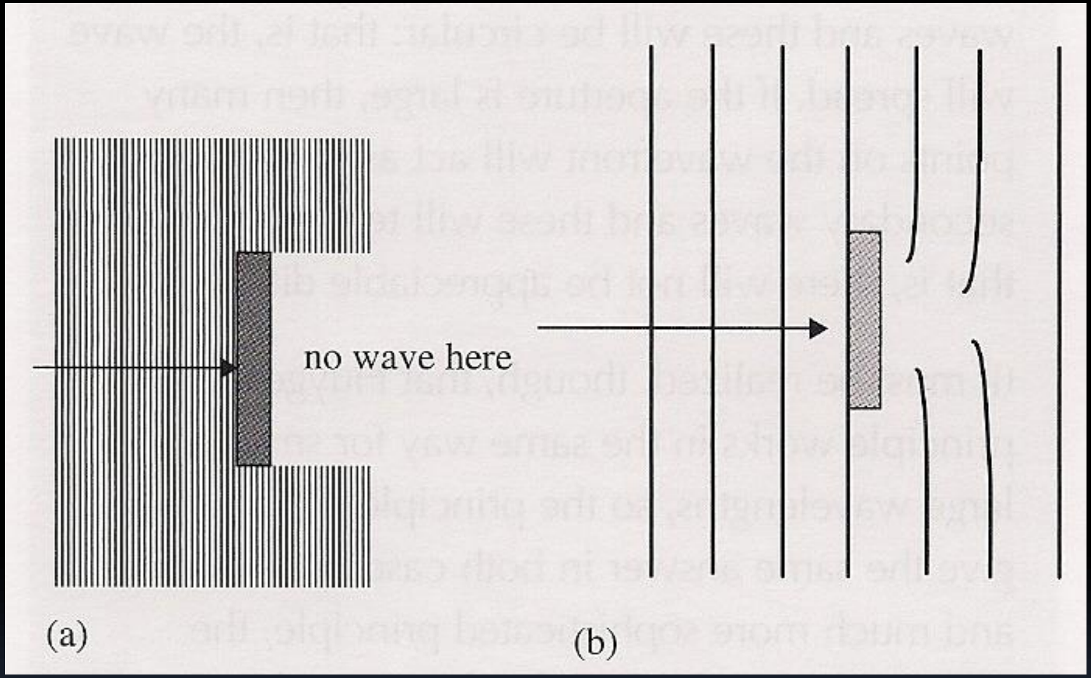
Diffraction:

- **If the wavelength is much smaller than the obstacle, no diffraction occurs and a shadow of the object is formed**



Diffraction:

- If the wavelength is comparable or larger than the object, diffraction takes place and the wave appears far from the object in the region where the shadow was expected



Interference

- Video: Interference of Light

Interference

- Interference is the result of the superposition of waves
- Destructive Interference
- Because these waves have the same amplitude and are 180° out of phase, they will completely cancel each other

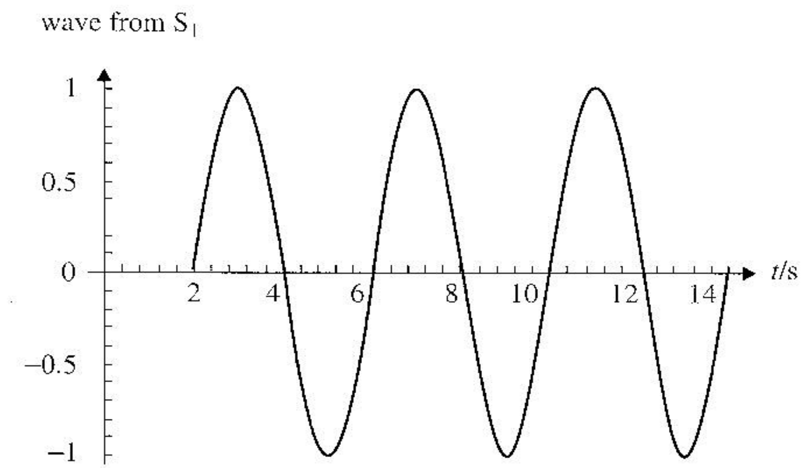


Figure 4.6 The first wave arrives at P 2 s after emission from the source.

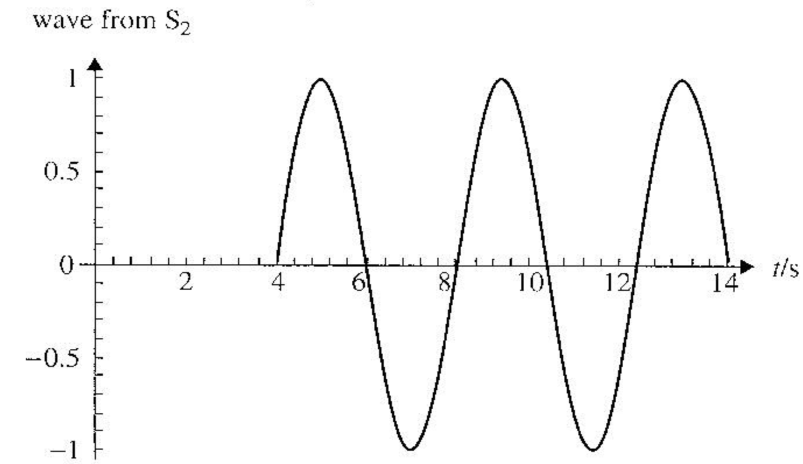
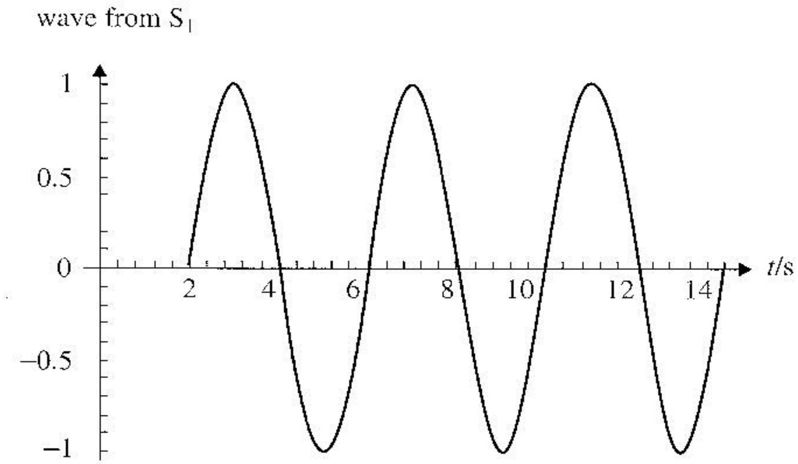


Figure 4.7 The second wave arrives at P 4 s after emission.

Interference

- We can also say that destructive interference occurs when two waves are out of phase by half a wavelength



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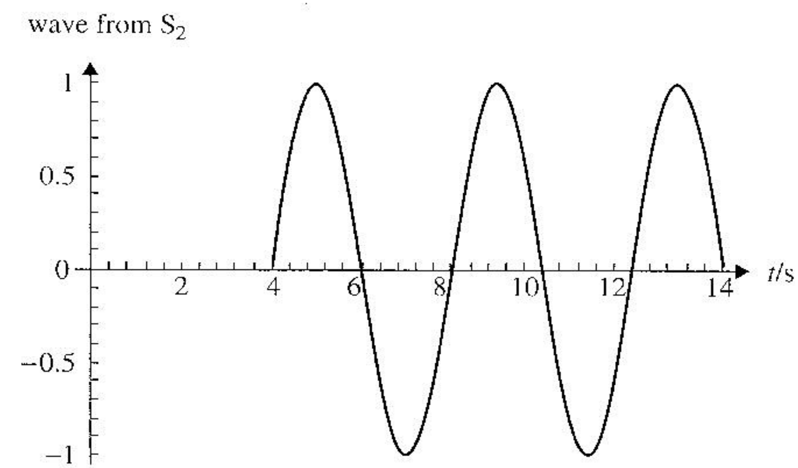


Figure 4.7 The second wave arrives at P 4 s after emission.

Interference

- Constructive Interference
- These waves have the same amplitude and are in phase with each other

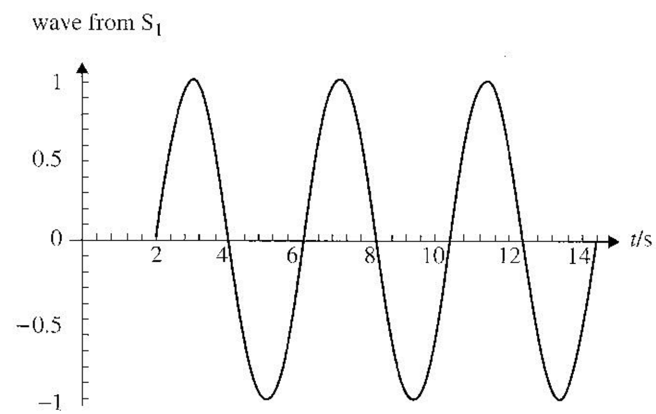


Figure 4.8 The first wave arrives at P 2 s after emission.

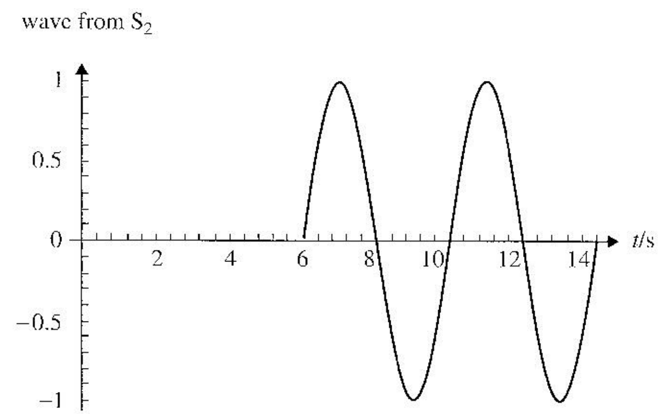


Figure 4.9 The second wave arrives at P 6 s after emission.

Interference

- **The result is the sum of their two amplitudes**

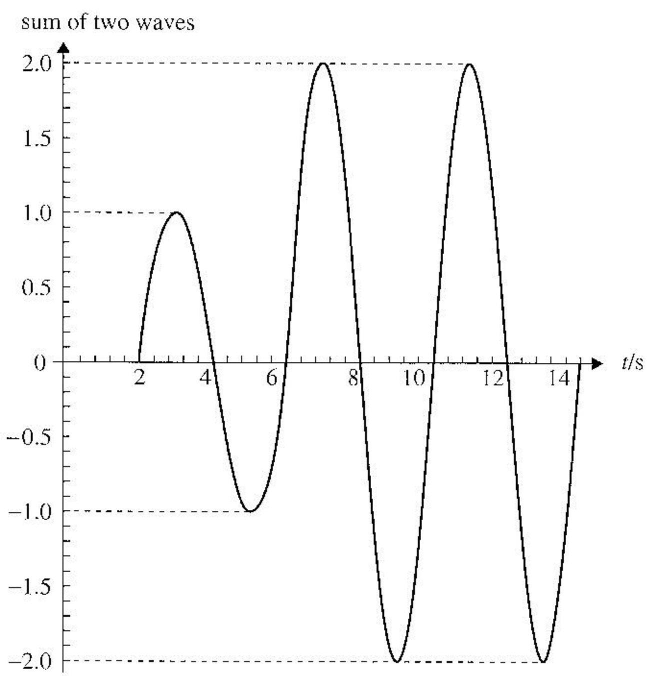
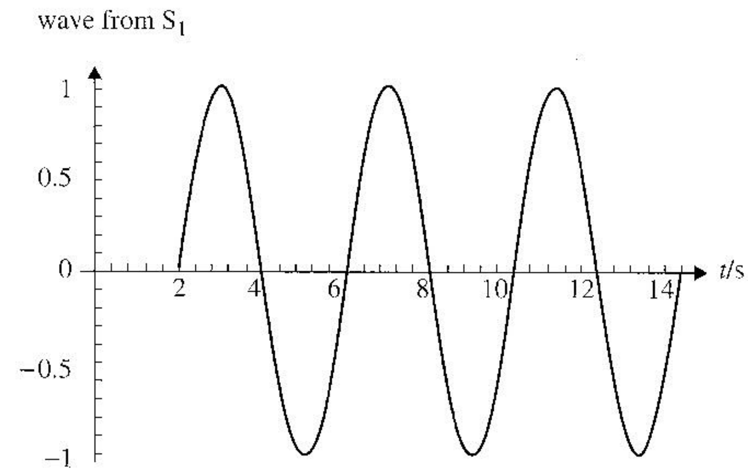


Figure 4.10 The sum of the waves from 6 s on (when both waves are present) has an amplitude that is double that of the individual waves.



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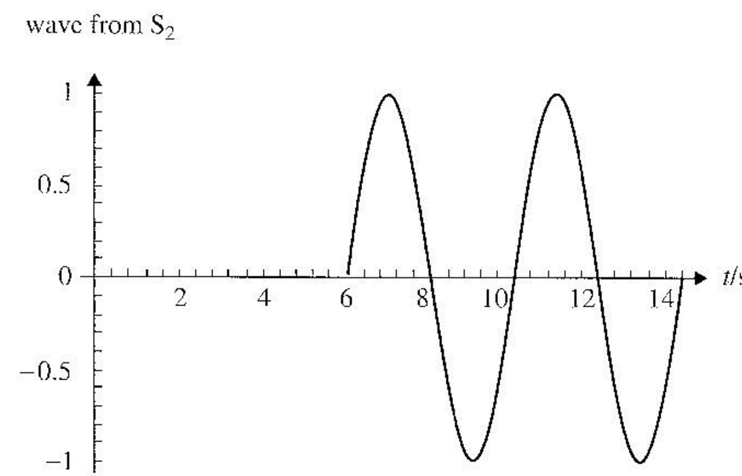
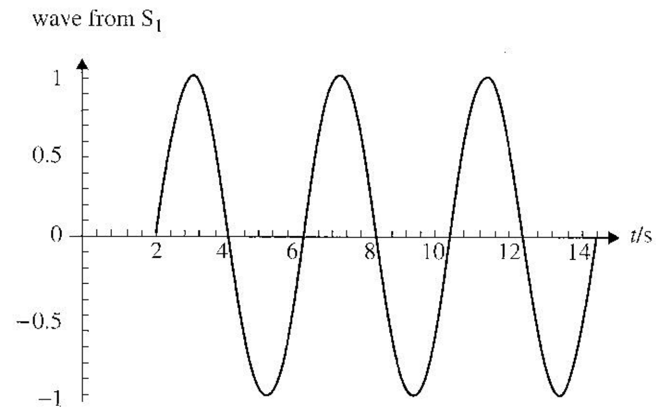


Figure 4.9 The second wave arrives at P 6 s after emission.

Interference

- Constructive Interference
- We can also say that the waves can start at different times or travel different distances, as long as the difference is some multiple of the wavelength (nλ), the waves will be in phase and constructive interference occurs



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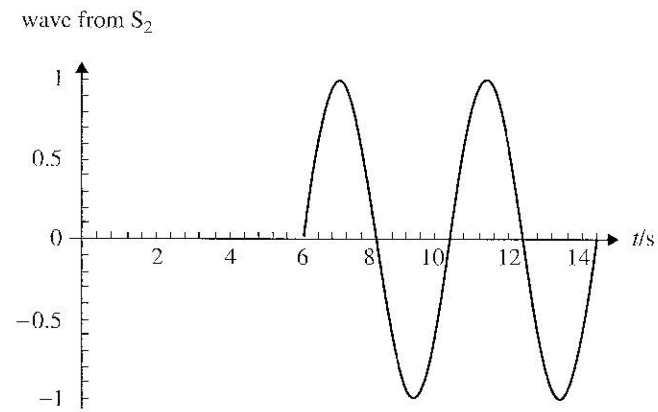
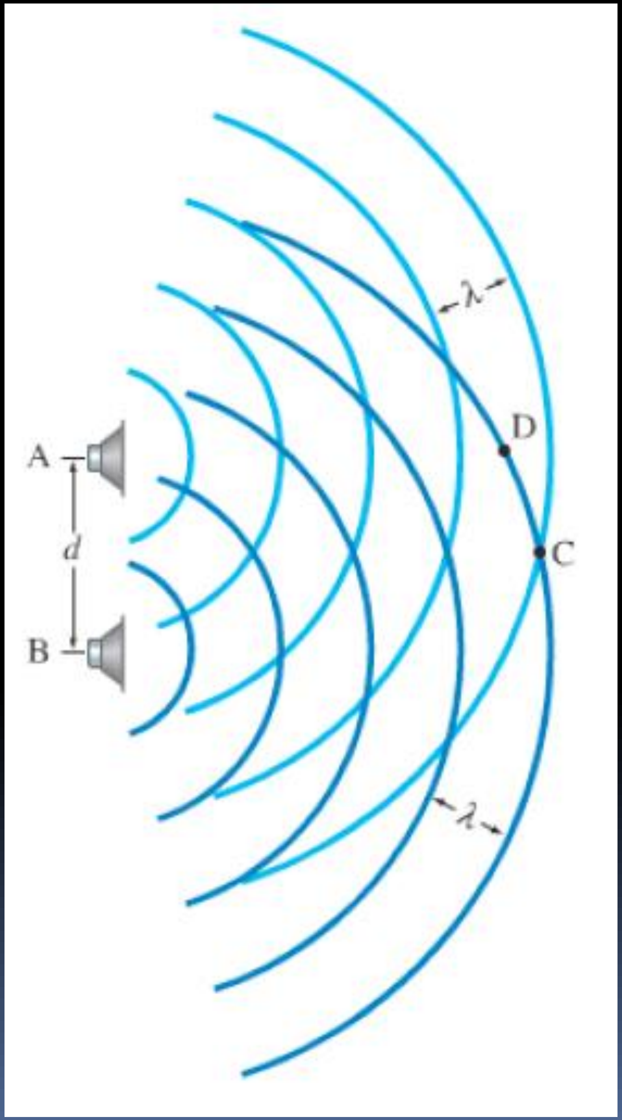


Figure 4.9 The second wave arrives at P 6 s after emission.

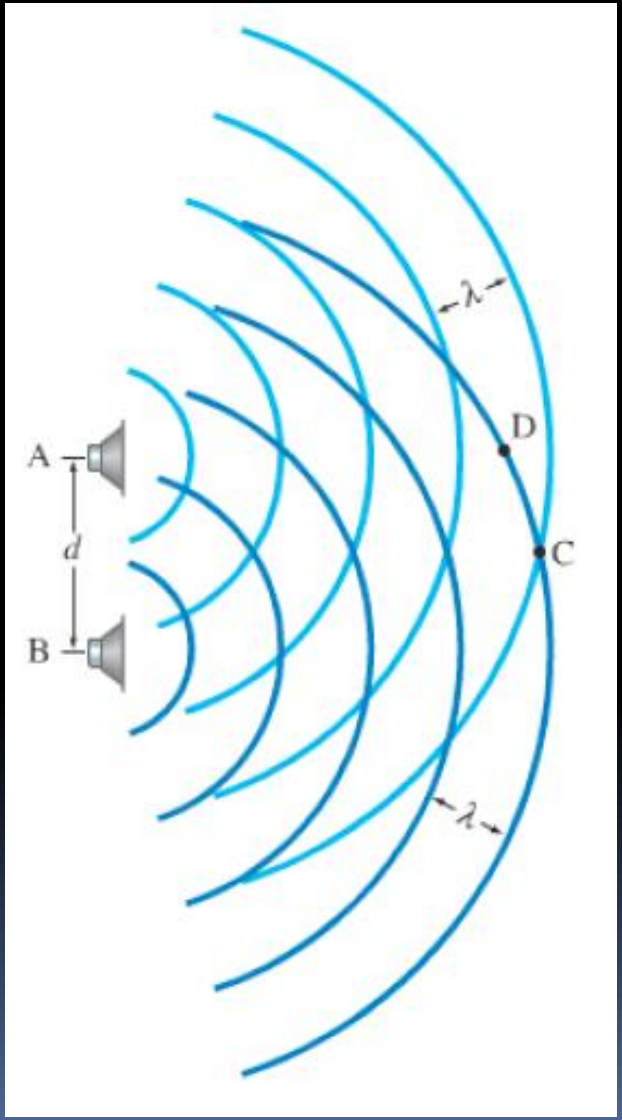
Two Source Interference

- Two speakers are playing the same sound at the same frequency and wavelength
- At point C, the observer is the same distance from each speaker
- The observer experiences the crests of both waves which creates a loud sound (constructive interference)



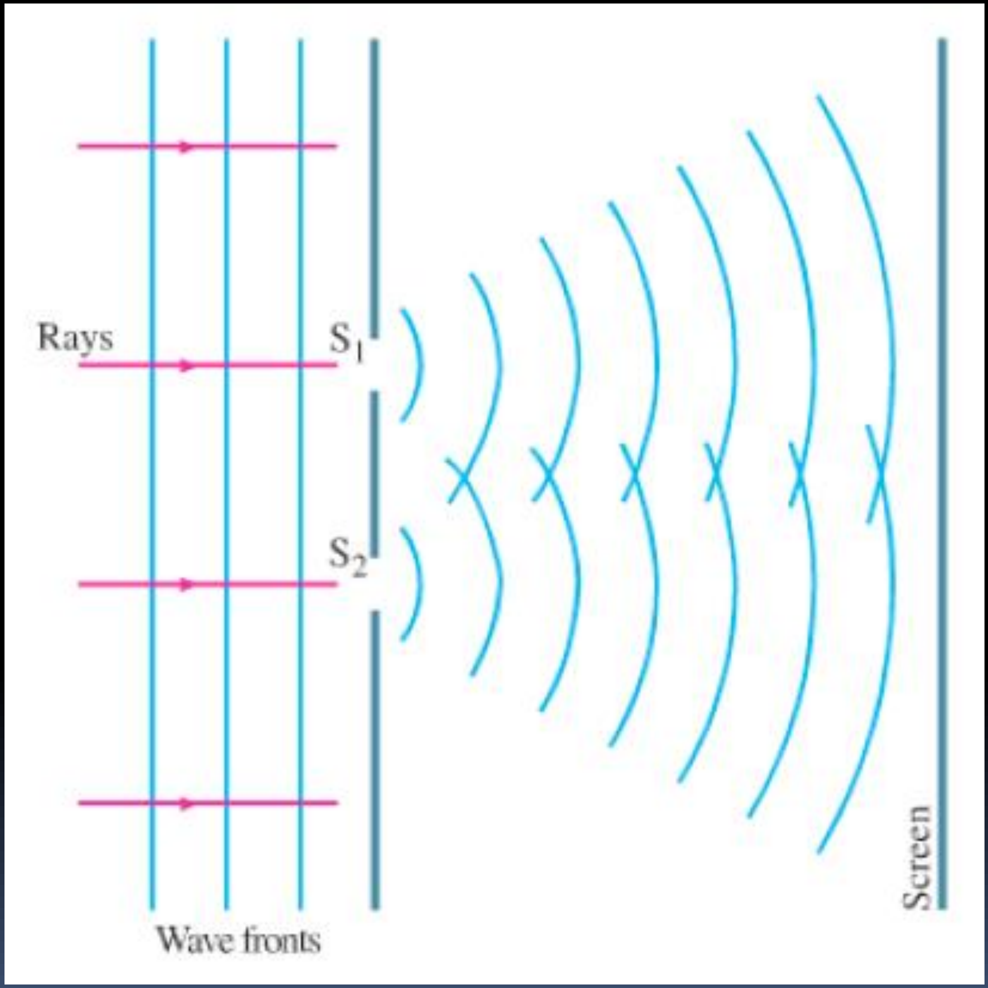
Two Source Interference

- At point D, the observer is at differences distance from each speaker
- Because the waves have to travel different distances to get to the observer, they are out of phase
- At point D, the waves are 180° out of phase, the observer gets the crest from A and the trough from B so complete destructive interference occurs



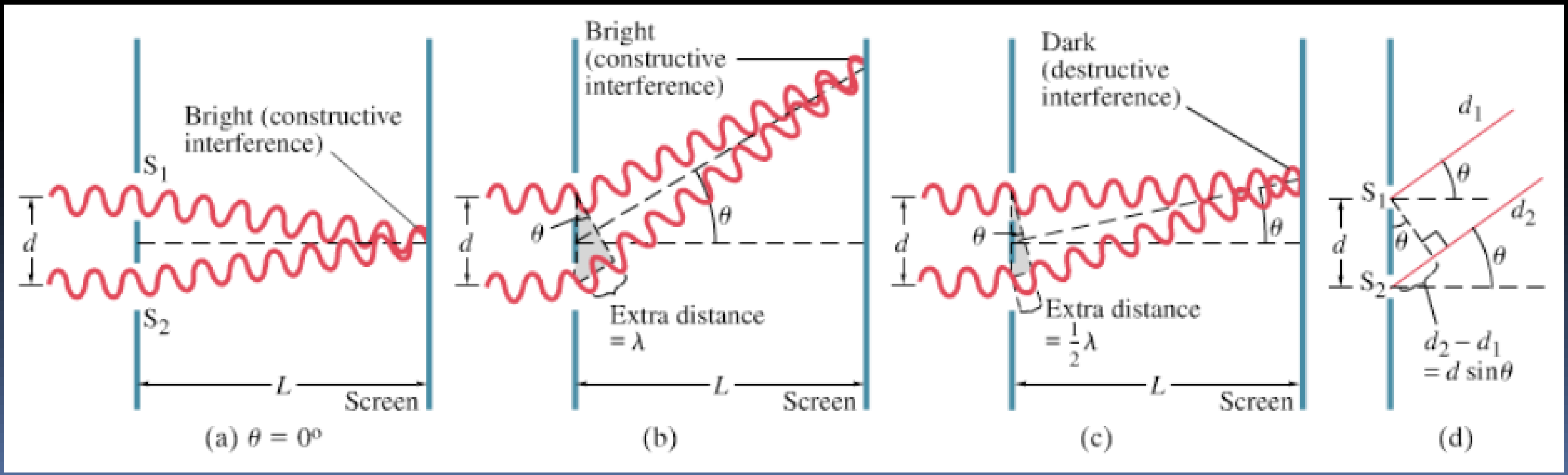
Two Source Interference

- The same effect occurs when light diffracts from two separate slits



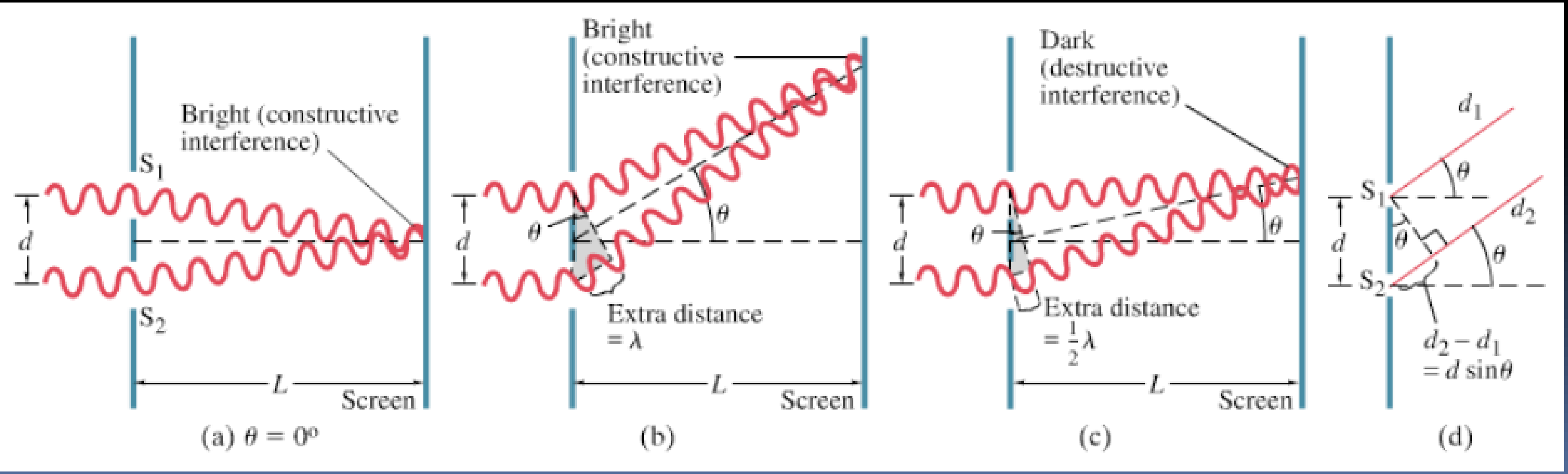
Two Source Interference

- Example (a): At a point directly in between the two slits, the distance travelled by the light wave is the same, so they are in phase, constructive interference occurs and the light is bright



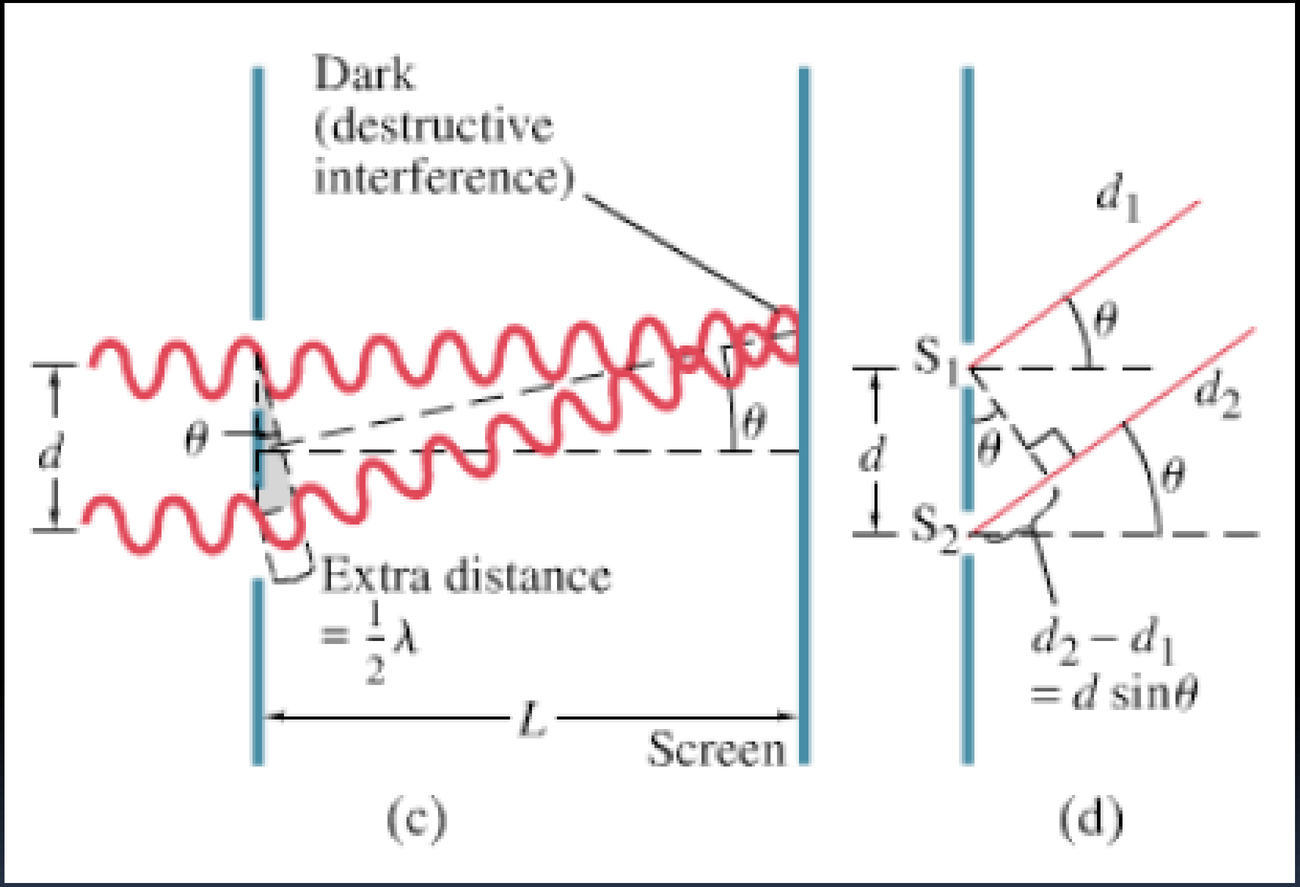
Two Source Interference

- Example (c):
  - The light from the bottom source has further to travel. When they meet, the waves are 180° out of phase, the waves cancel each other out, and there is a dark spot on the screen.



Two Source Interference

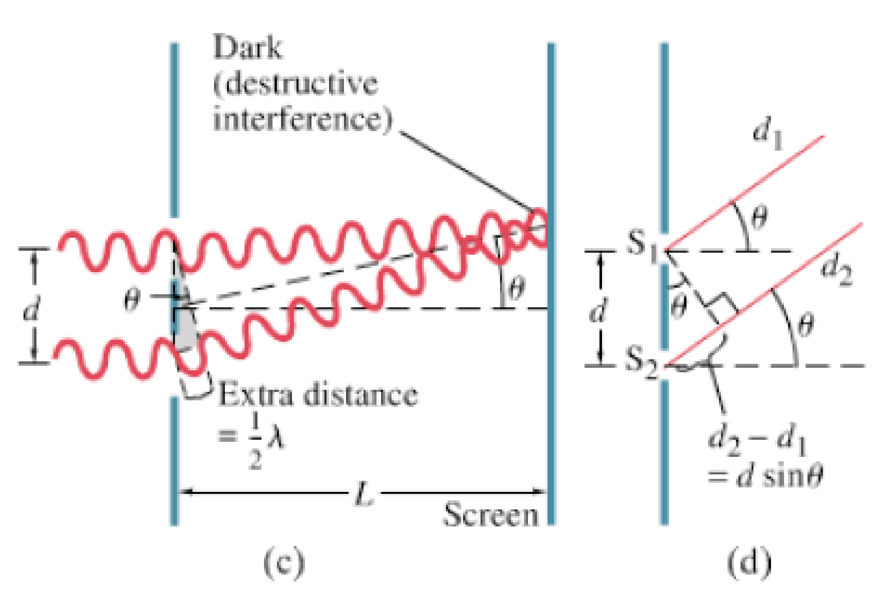
- Example (c):
  - Diagram (d) shows the differences between the distances travelled



$$d_2 - d_1 = d \sin\theta$$

Two Source Interference

- Example (c):
  - θ is the diffraction angle
  - d is the distance between the two slits
  - If the path difference (d_2-d_1 or d sin θ) is equal to ½ wavelength [(n + 1/2)λ], you have destructive interference

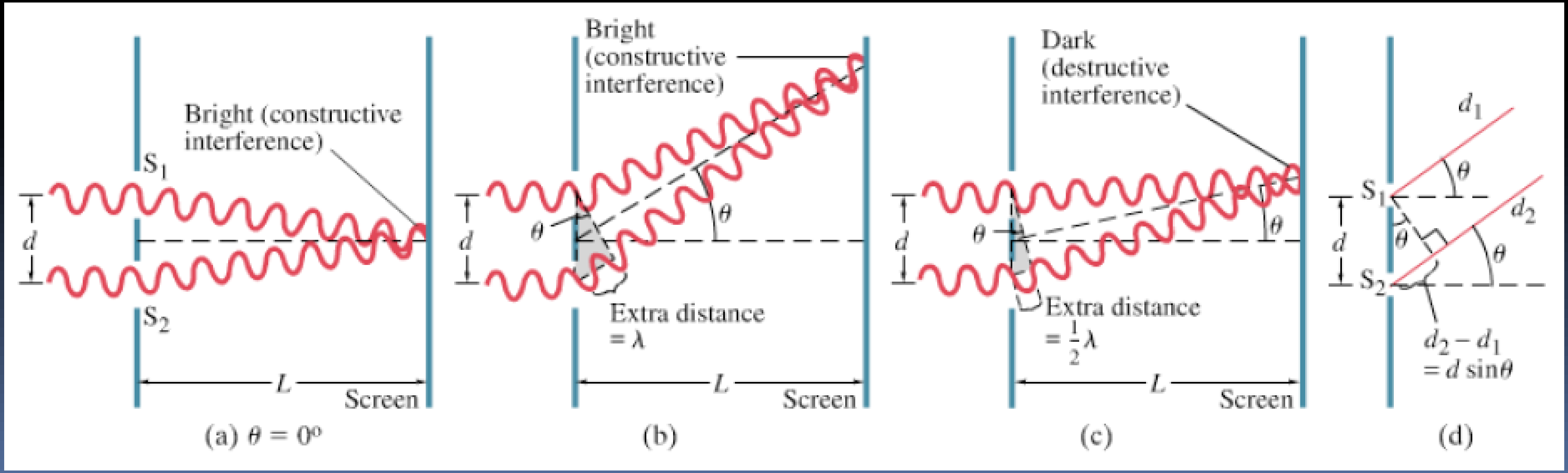


  - If the path difference is equal to some multiple of the wavelength [nλ], you have constructive interference

$$d_2 - d_1 = d \sin\theta$$

Two Source Interference

- Example (b):
  - The path difference is equal to 1 wavelength so constructive interference occurs
  - The same would happen with path differences of 2λ, 3λ, 4λ, . . .



Two Source Interference

- Example (b):
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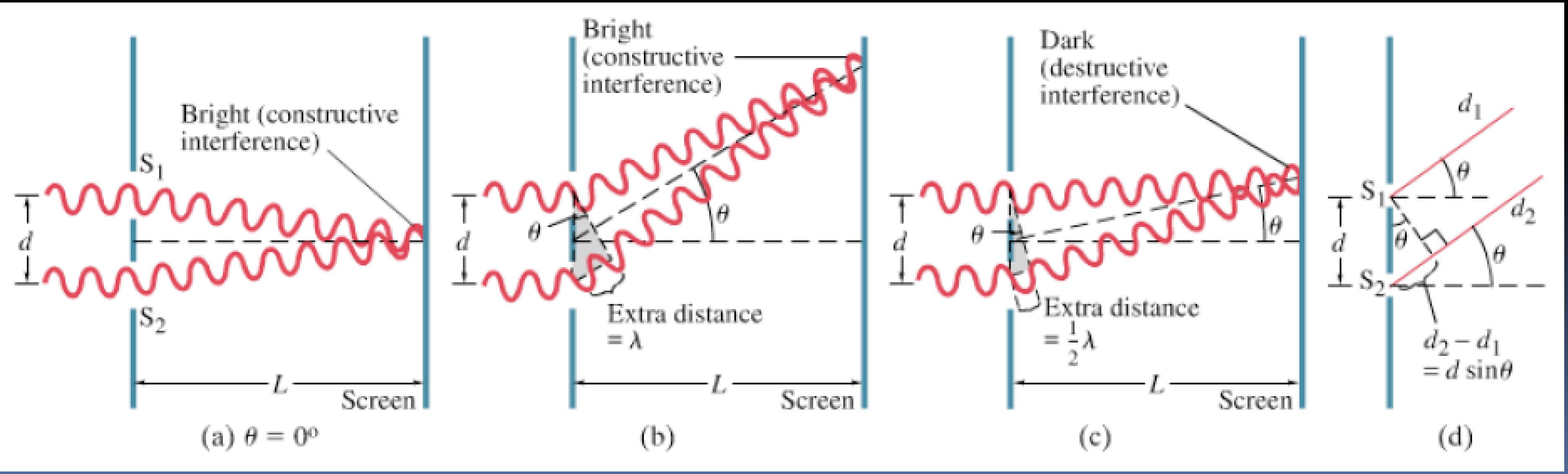
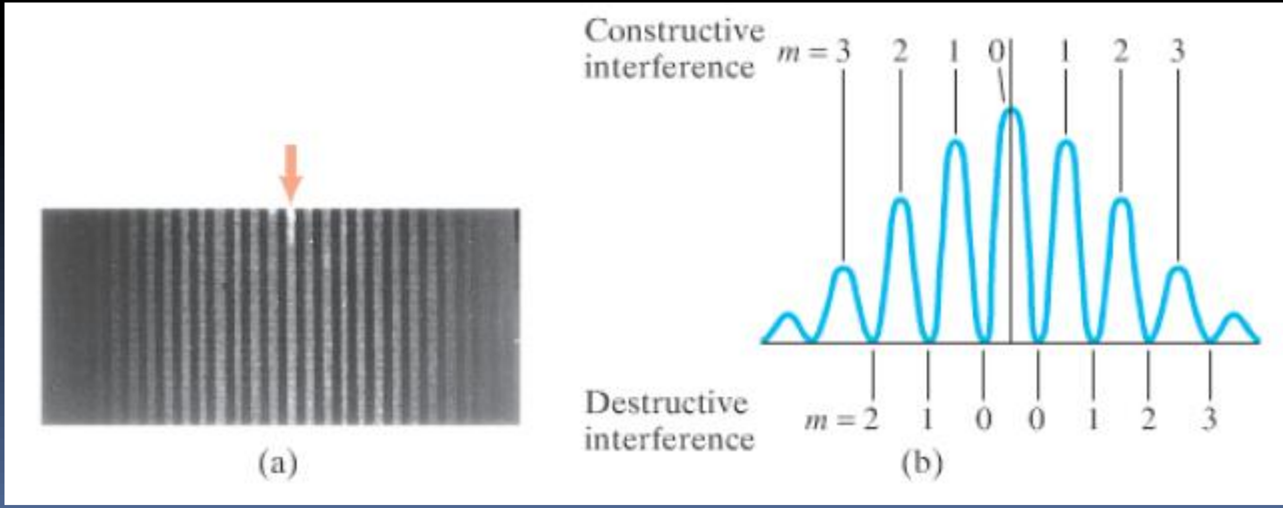


Two Source Interference

- The resulting pattern looks something like the pictures below
  - (a) is what it would look like on a screen
  - (b) is a graph of the intensities versus distances from the central maximum
  - ***How can we determine the distances between the maxima?***

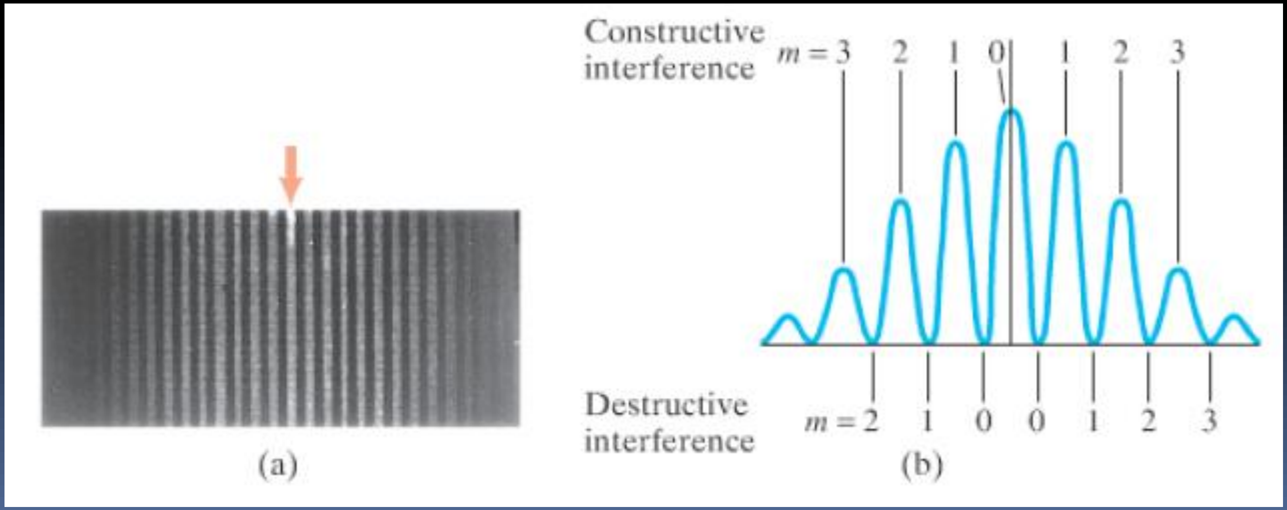


(a) (b)

Two Source Interference

- ***s*** is the distance between peaks, or maxima
- ***λ*** is the wavelength
- ***D*** is the distance from the slits to the screen
- ***d*** is the distance between the slits

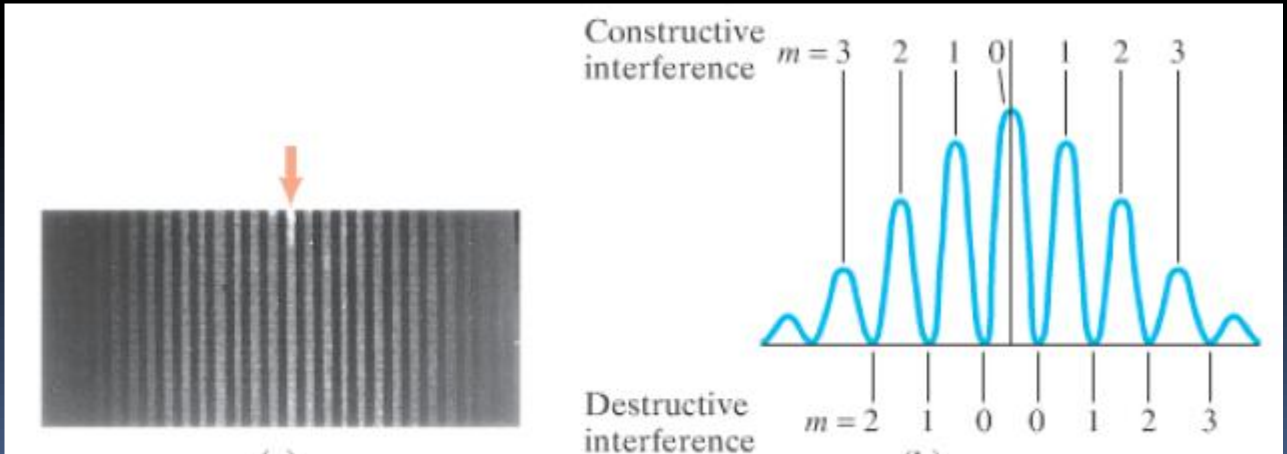
$$s = \frac{\lambda D}{d}$$



Two Source Interference

- ***You should be able to reproduce this graph with computed distances between maxima***
- ***The intensity and rate of decrease are arbitrary but should be representative***

$$s = \frac{\lambda D}{d}$$



(a)
(b)

Piece a‘ Cake, Right?

Understandings:

- Reflection and refraction
- Snell's law, critical angle and total internal reflection
- Diffraction through a single-slit and around objects
- Interference patterns
- Double-slit interference
- Path difference

Applications And Skills:

- Sketching and interpreting incident, reflected and transmitted waves at boundaries between media
- Solving problems involving reflection at a plane interface

Applications And Skills:

- Solving problems involving Snell's law, critical angle and total internal reflection
- Determining refractive index experimentally

Applications And Skills:

- Qualitatively describing the diffraction pattern formed when plane waves are incident normally on a single-slit
- Quantitatively describing double-slit interference intensity patterns

Data Booklet Reference:

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

$$s = \frac{\lambda D}{d}$$

Data Booklet Reference:

- Constructive Interference: path difference =

$$n\lambda$$

- Destructive Interference: path difference =

$$\left(n+\frac{1}{2}\right)\lambda$$

Utilization:

- A satellite footprint on Earth is governed by the diffraction at the dish on the satellite
- Applications of the refraction and reflection of light range from the simple plane mirror through the medical endoscope and beyond. Many of these applications have enabled us to improve and extend our sense of vision

Utilization:

- The simple idea of the cancellation of two coherent light rays reflecting from two surfaces leads to data storage in compact discs and their successors
- The physical explanation of the rainbow involves refraction and total internal reflection. The bright and dark bands inside the rainbow, supernumeraries, can be explained only by the wave nature of light and diffraction

Essential Idea:

- Waves interact with media and each other in a number of ways that can be unexpected and useful.

QUESTIONS?

Homework

#25-31