Section 4.4

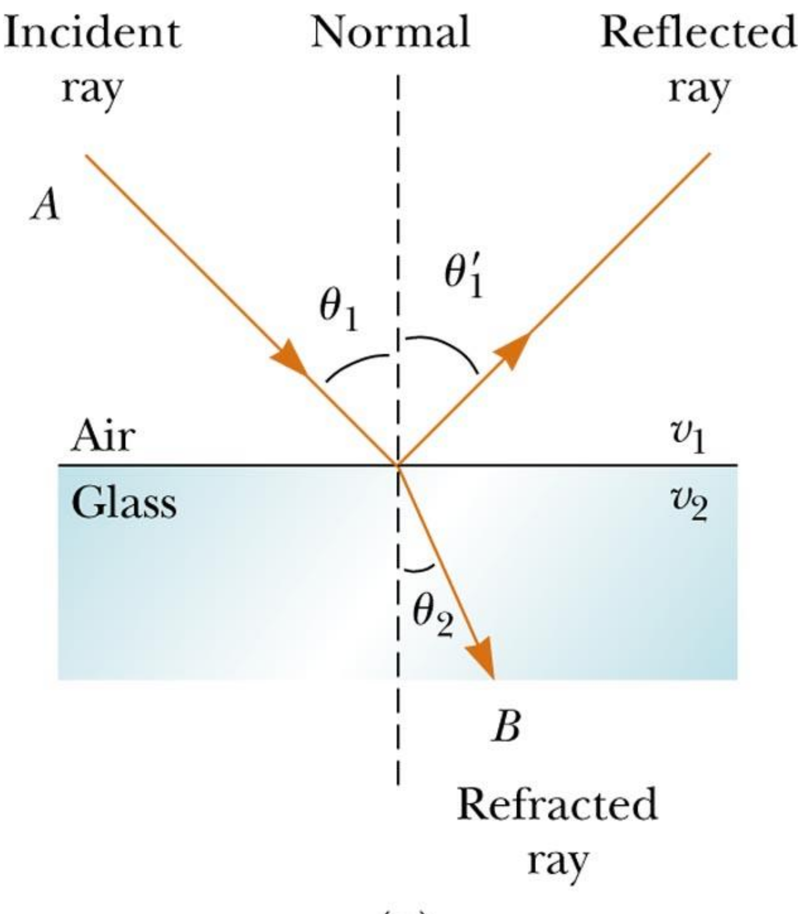
Wave Behaviour

Refraction of Light

- The bending of light as it travels from one medium to another is call **refraction.**
- As a light ray travels from one medium into another medium where its speed is different, the light ray will change its direction unless it travels along the normal.

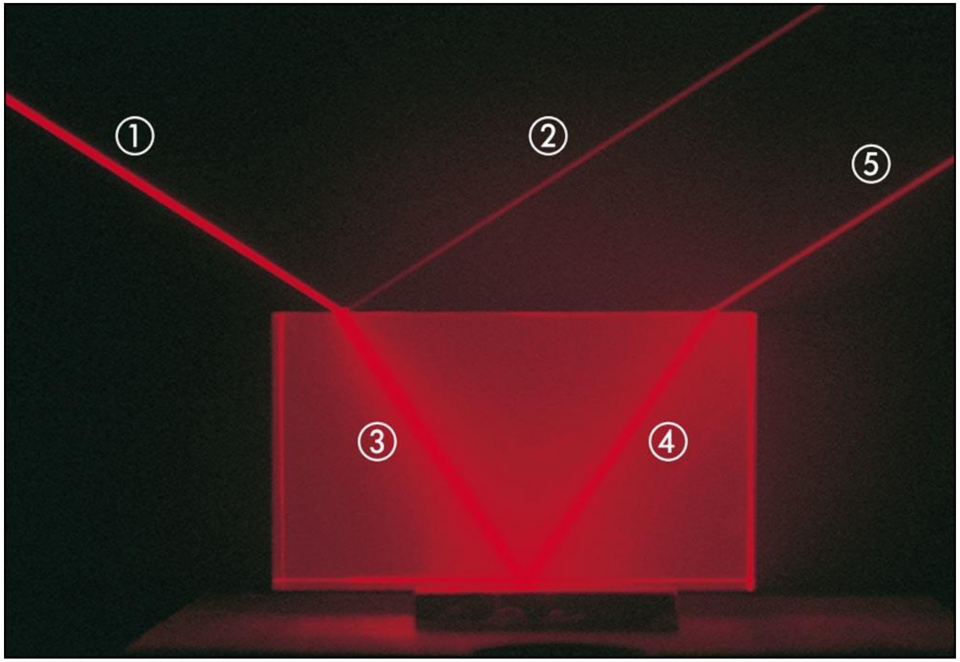
Refraction of Light, cont

- The incident ray, the reflected ray, the refracted ray, and the normal all lie on the same plane
- The angle of refraction, θ_2, depends on the properties of the medium

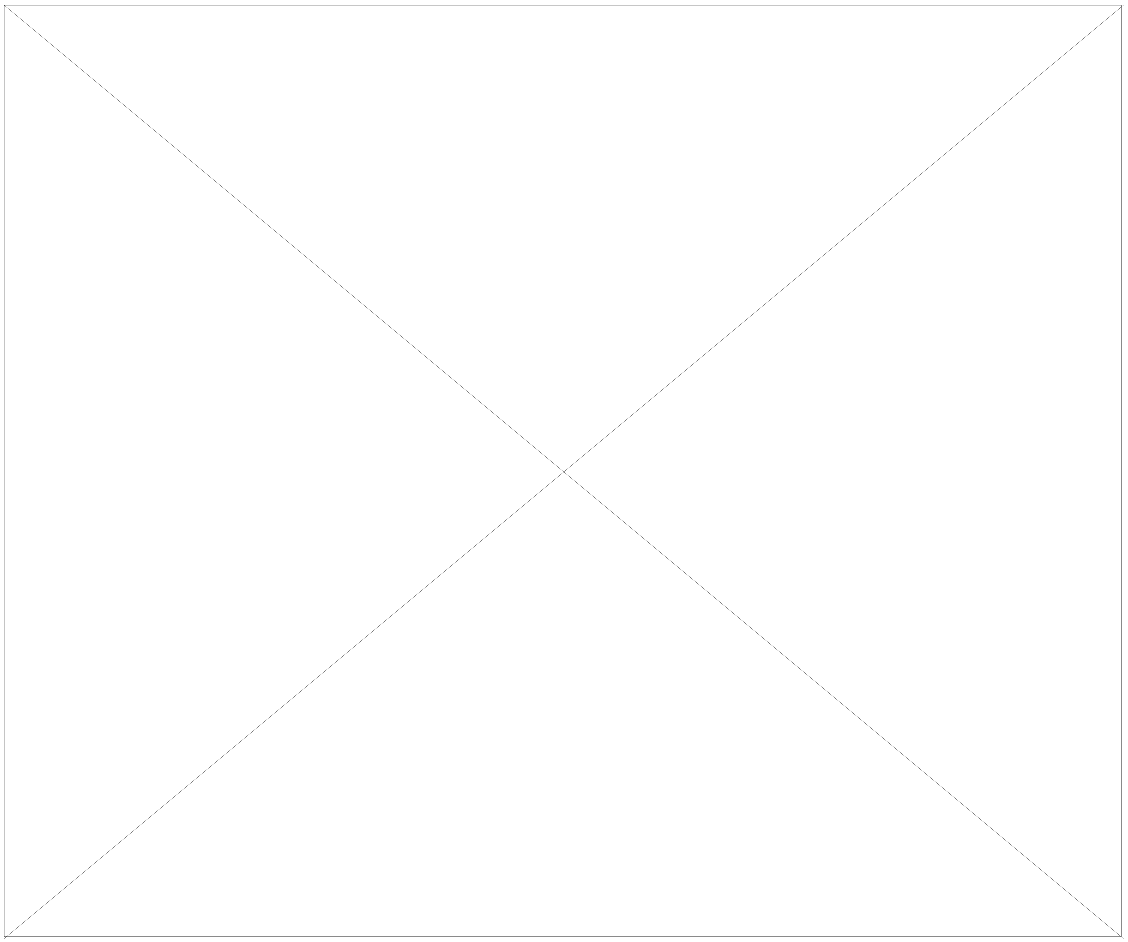


Following the Reflected and Refracted Rays

- Ray ① is the incident ray
- Ray ② is the reflected ray
- Ray ③ is refracted into the lucite
- Ray ④ is internally reflected in the lucite
- Ray ⑤ is refracted as it enters the air from the lucite



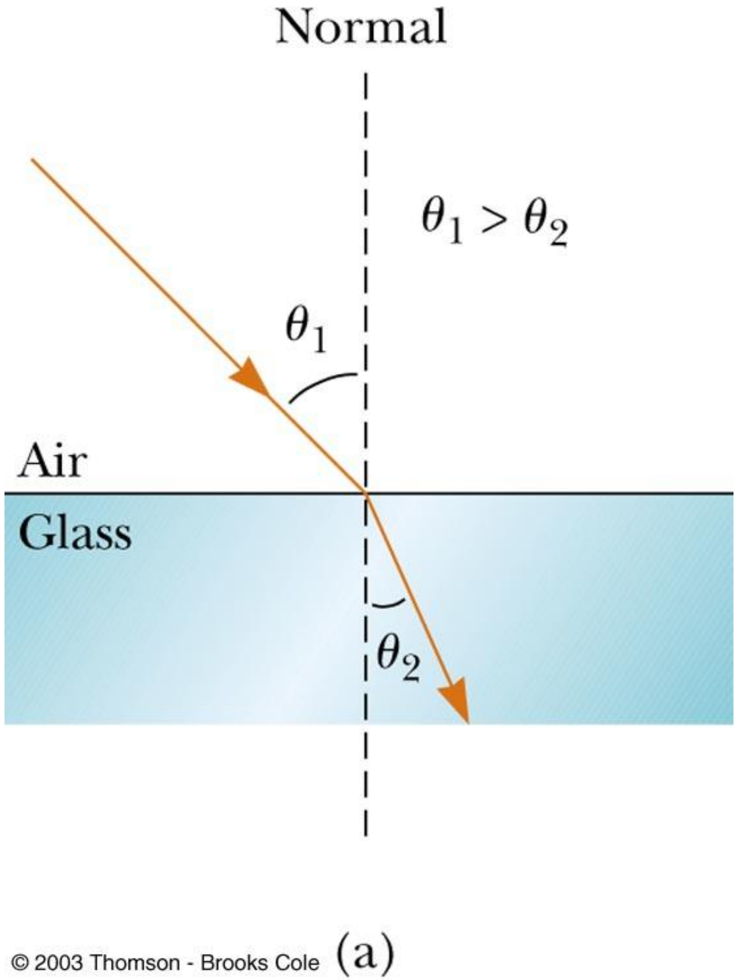
Refraction



Wave Model of Refraction

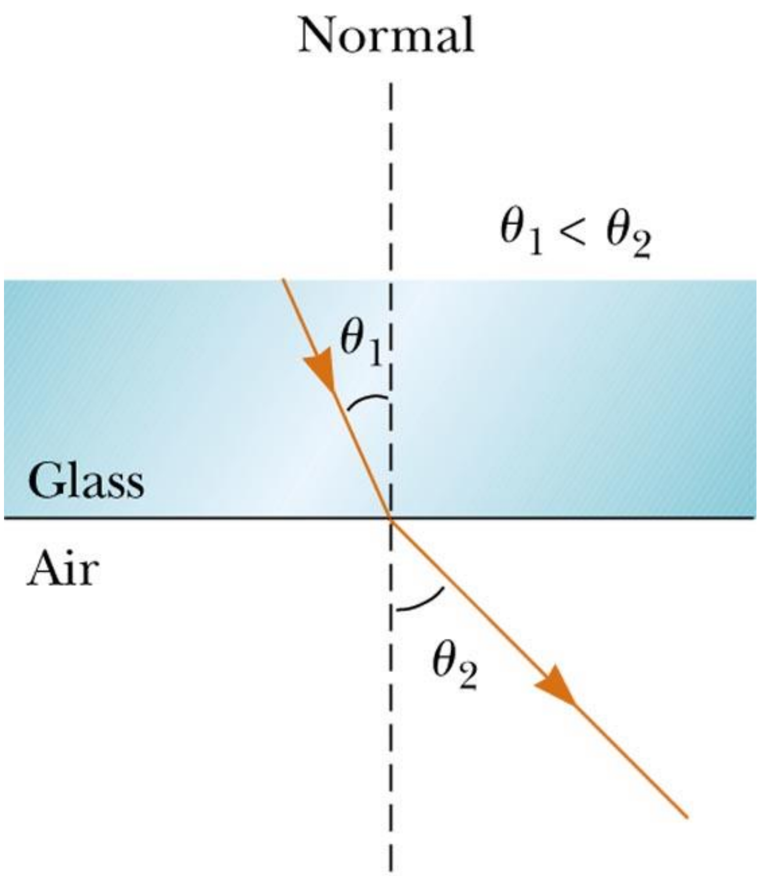
Refraction Details, 1

- Light may refract into a material where its speed is lower
- The angle of refraction is less than the angle of incidence
  - The ray bends *toward* the normal



Refraction Details, 2

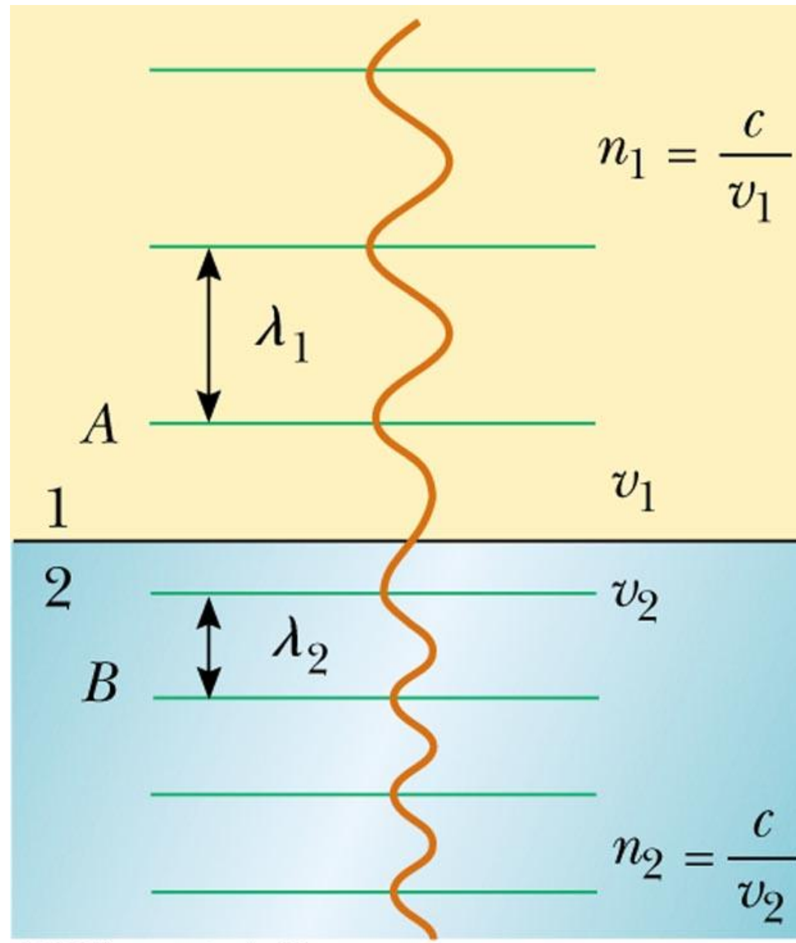
- Light may refract into a material where its speed is higher
- The angle of refraction is greater than the angle of incidence
  - The ray bends *away from* the normal



 (b)

Frequency Between Media

- As light travels from one medium to another, *its frequency does not change*
  - Both the wave speed and the wavelength do change
  - The wavefronts do not pile up, nor are created or destroyed at the boundary, so f must stay the same



The Law of Refraction

- The **index of refraction** for a substance is the ratio of the speed of light in a vacuum to the speed of light in that substance.

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

$$\text{index of refraction} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in medium}}$$

Indices of Refraction for Various Substances

Solids at 20°C	*n*
Cubic zirconia	2.20
Diamond	2.419
Fluorite	1.434
Fused quartz	1.458
Glass, crown	1.52
Glass, flint	1.66
Ice (at 0°C)	1.309
Polystyrene	1.49
Sodium chloride	1.544
Zircon	1.923

Liquids at 20°C	*n*
Benzene	1.501
Carbon disulfide	1.628
Carbon tetrachloride	1.461
Ethyl alcohol	1.361
Glycerine	1.473
Water	1.333

Gases at 0°C, 1 atm	*n*
Air	1.000 293
Carbon dioxide	1.000 450

*measured with light of vacuum wavelength = 589 nm

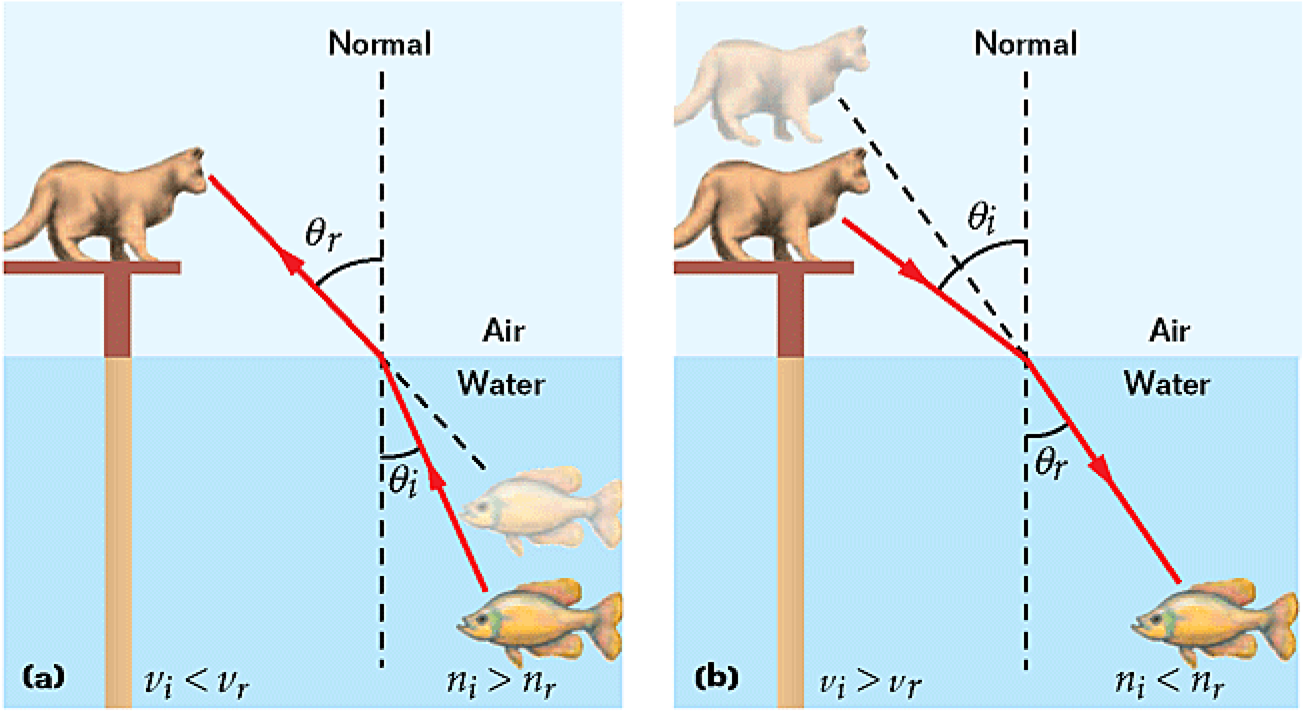
The Law of Refraction, *continued*

- Objects appear to be in different positions due to refraction.

- Snell's Law determines the angle of refraction.

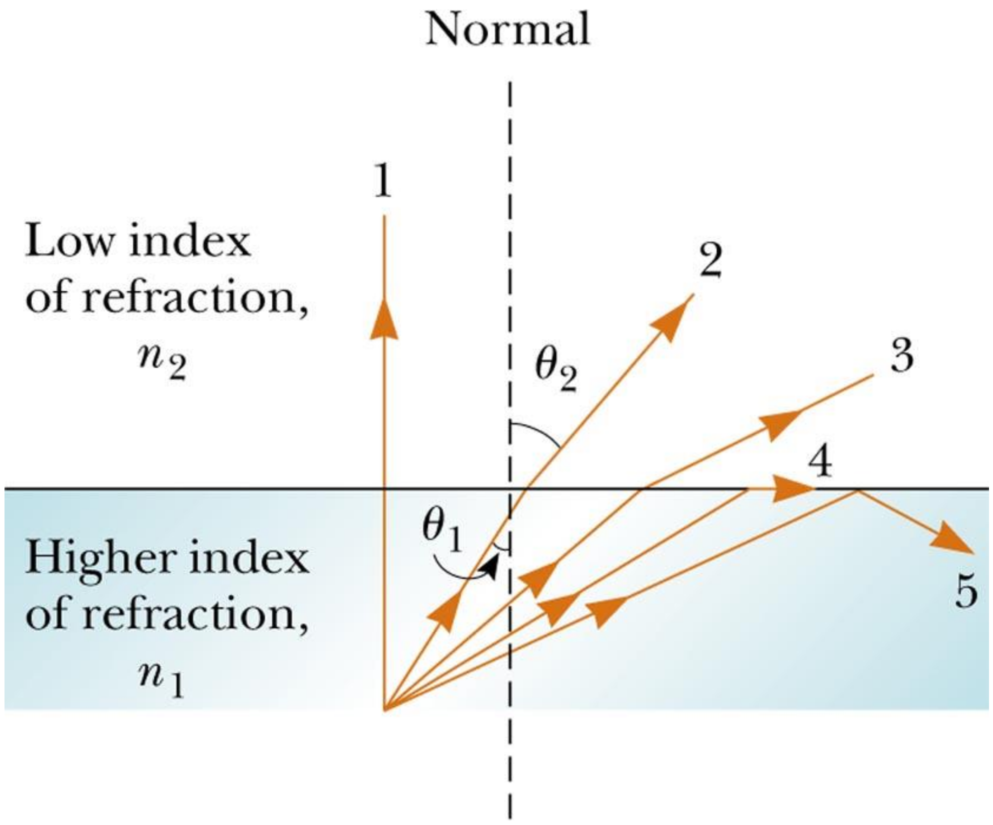
$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1} = \frac{f\lambda_2}{f\lambda_1}$$

Image Position for Objects in Different Media



Total Internal Reflection

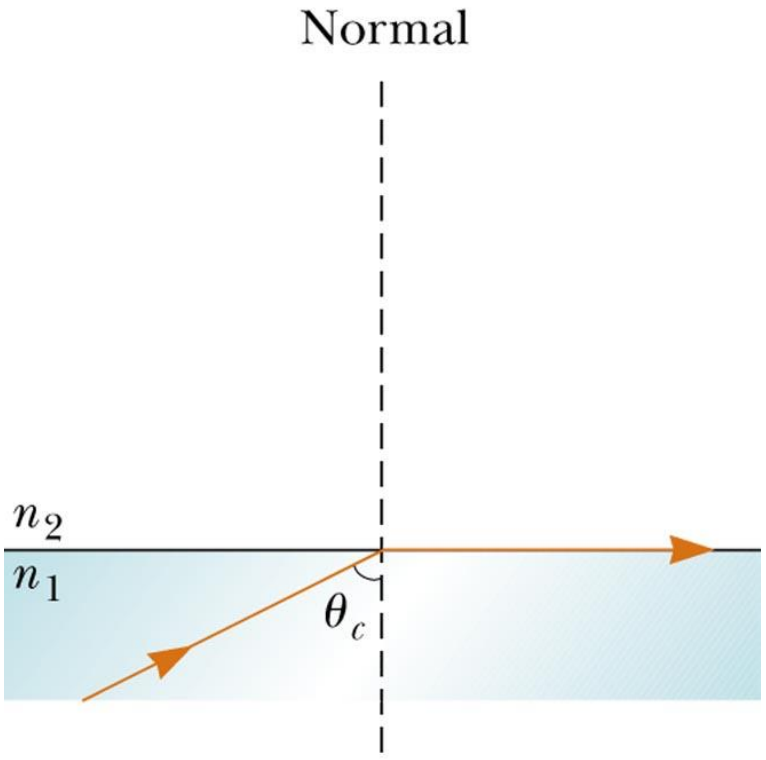
- *Total internal reflection* can occur when light attempts to move from a medium with a high index of refraction to one with a lower index of refraction
  - Ray 5 shows internal reflection



(a)

Critical Angle

- A particular angle of incidence will result in an angle of refraction of 90°
  - This angle of incidence is called the *critical angle*



(b)

$$\sin\theta_C = \frac{n_2}{n_1} \quad \textit{for } n_1 > n_2$$

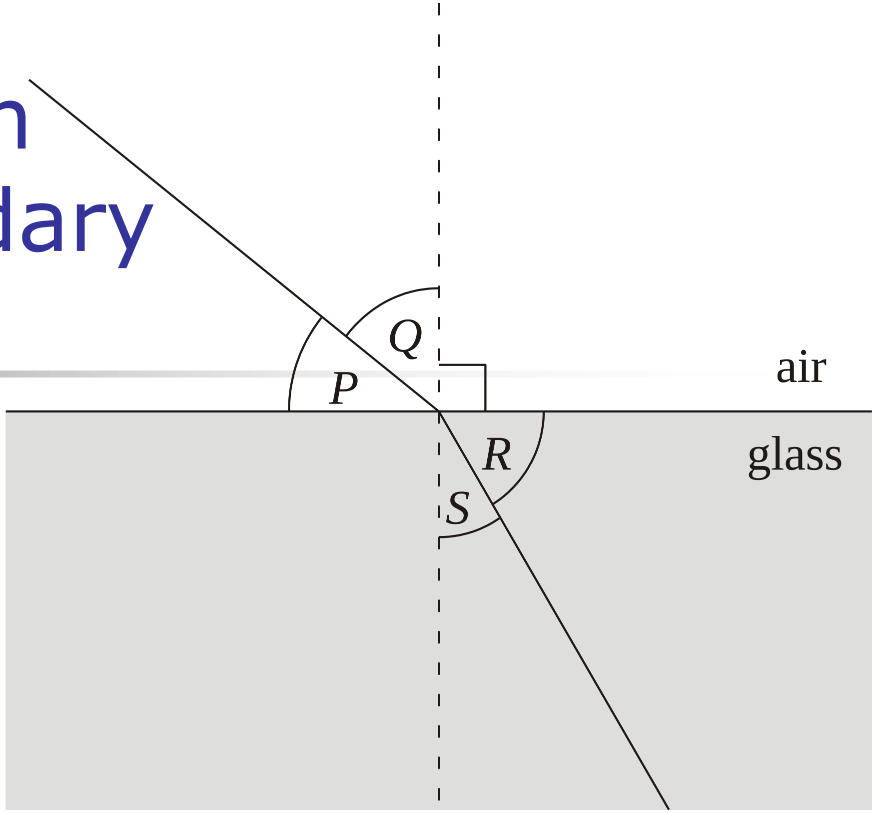
Critical Angle, cont

- For angles of incidence *greater* than the critical angle, the beam is entirely reflected at the boundary
  - This ray obeys the Law of Reflection at the boundary
- Total internal reflection occurs only when light attempts to move from a medium of higher index of refraction to a medium of lower index of refraction

Which of the following correctly describes the change, if any, in the speed, wavelength and frequency of a light wave as it passes from air into glass?

	Speed	Wavelength	Frequency
A.	decreases	decreases	unchanged
B.	decreases	unchanged	decreases
C.	unchanged	increases	decreases
D.	increases	increases	unchanged

Light is incident on an air-glass boundary as shown below.



Which **one** of the following is a correct statement of Snell's law?

A. sin *P* = constant x sin *R*

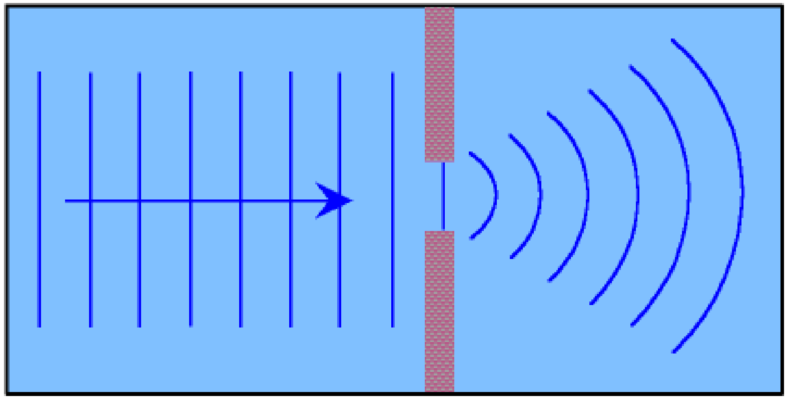
B. sin *P* = constant x sin *S*

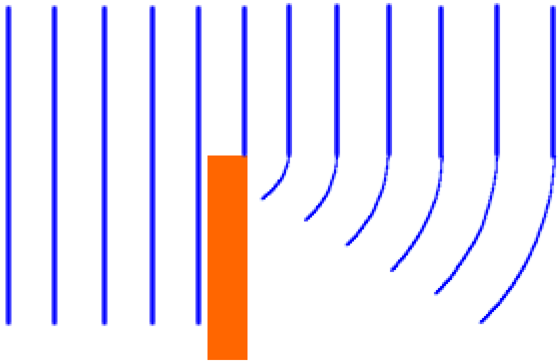
C. sin *Q* = constant x sin *R*

D. sin *Q* = constant x sin *S*

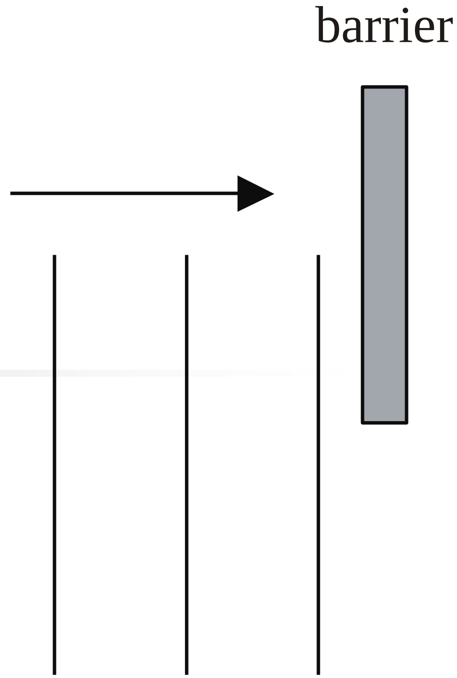
Diffraction

- Waves spread out after they pass through slits
- This spreading out of light from its initial line of travel is called *diffraction*
  - In general, diffraction occurs when waves pass through small openings, around obstacles or by sharp edges

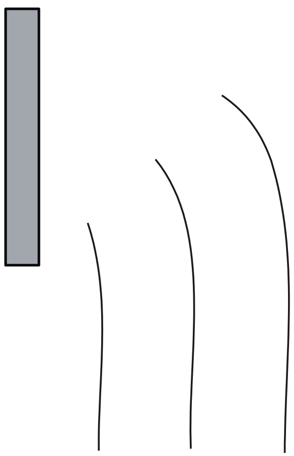




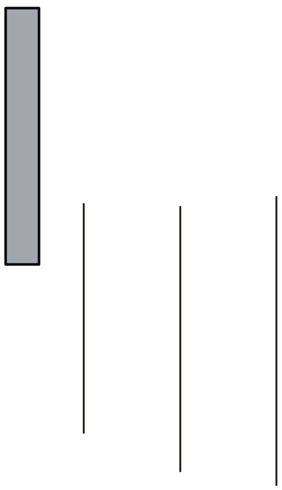
Plane wavefronts are incident on a barrier as shown at right.



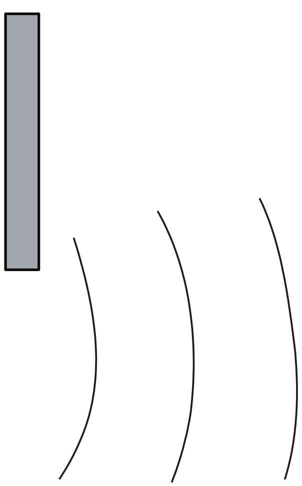
A.



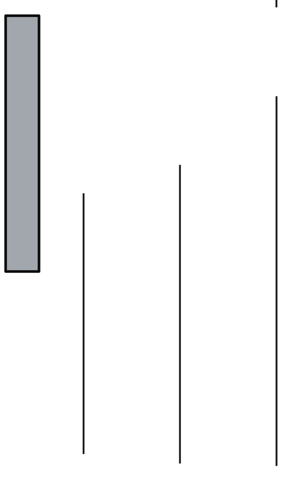
B.



C.



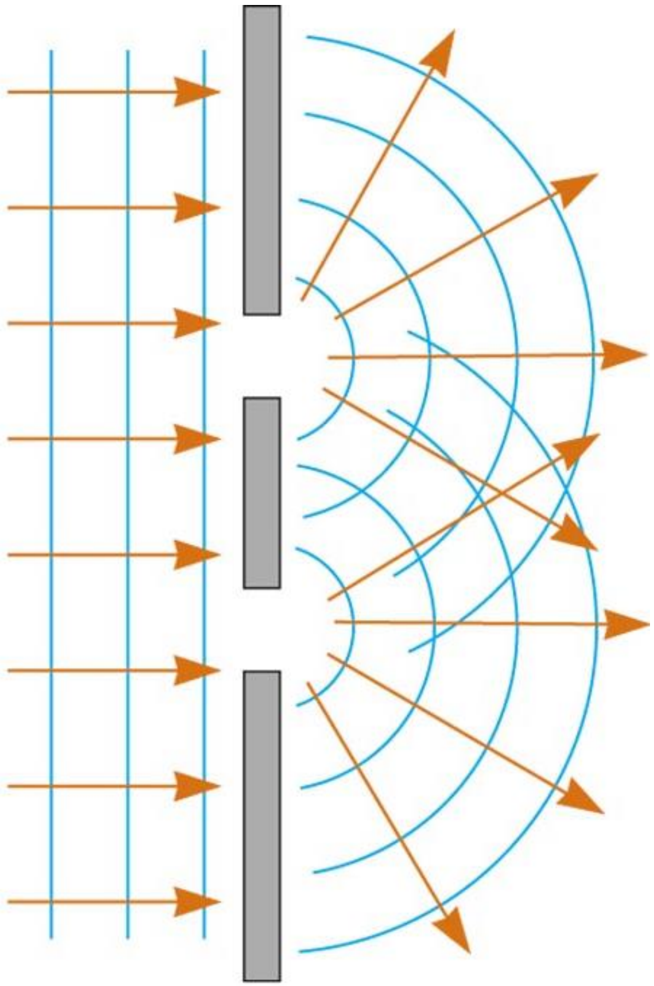
D.



Which of the following best shows the shape of the wavefronts on the other side of the barrier?

Diffraction, 2

- When waves pass through two adjacent openings (dual slit), constructive and destructive interference occurs.

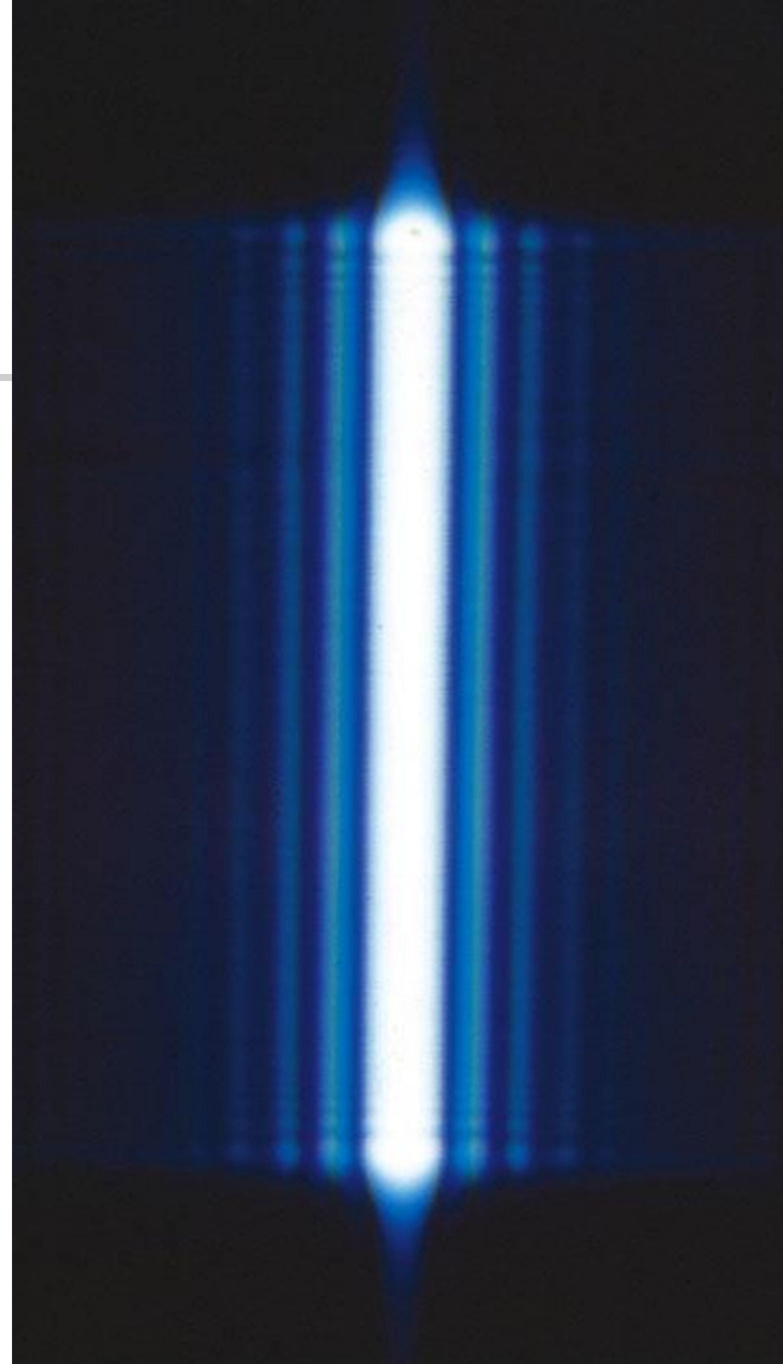


Diffraction, 3

- A single slit placed between a distant light source and a screen produces a diffraction pattern
  - It will have a broad, intense central band
  - The central band will be flanked by a series of narrower, less intense secondary bands
    - Called secondary maxima
  - The central band will also be flanked by a series of dark bands
    - Called minima

Diffraction, 4

- The results of the single slit cannot be explained by geometric optics
  - Geometric optics would say that light rays traveling in straight lines should cast a sharp image of the slit on the screen

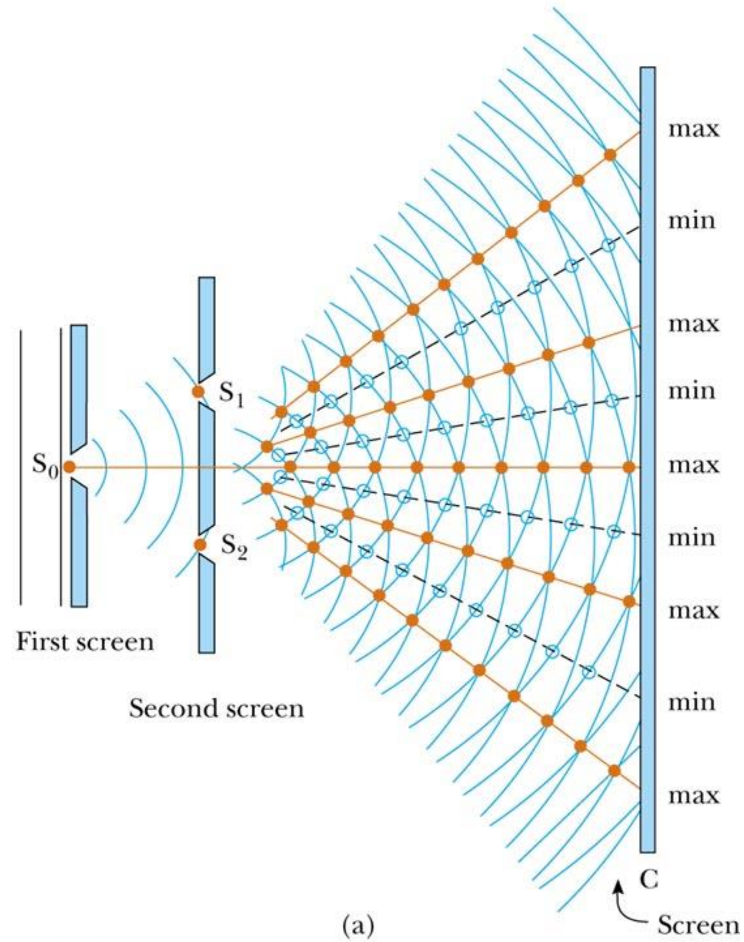


Young's Double Slit Experiment

- Thomas Young first demonstrated interference in light waves from two sources in 1801
- Light is incident on a screen with a narrow slit, S_o
- The light waves emerging from this slit arrive at a second screen that contains two narrow, parallel slits, S_1 and S_2

Young’s Double Slit Experiment, Diagram

- The narrow slits, S_1 and S_2 act as sources of waves
- The waves emerging from the slits originate from the same wave front and therefore are always in phase

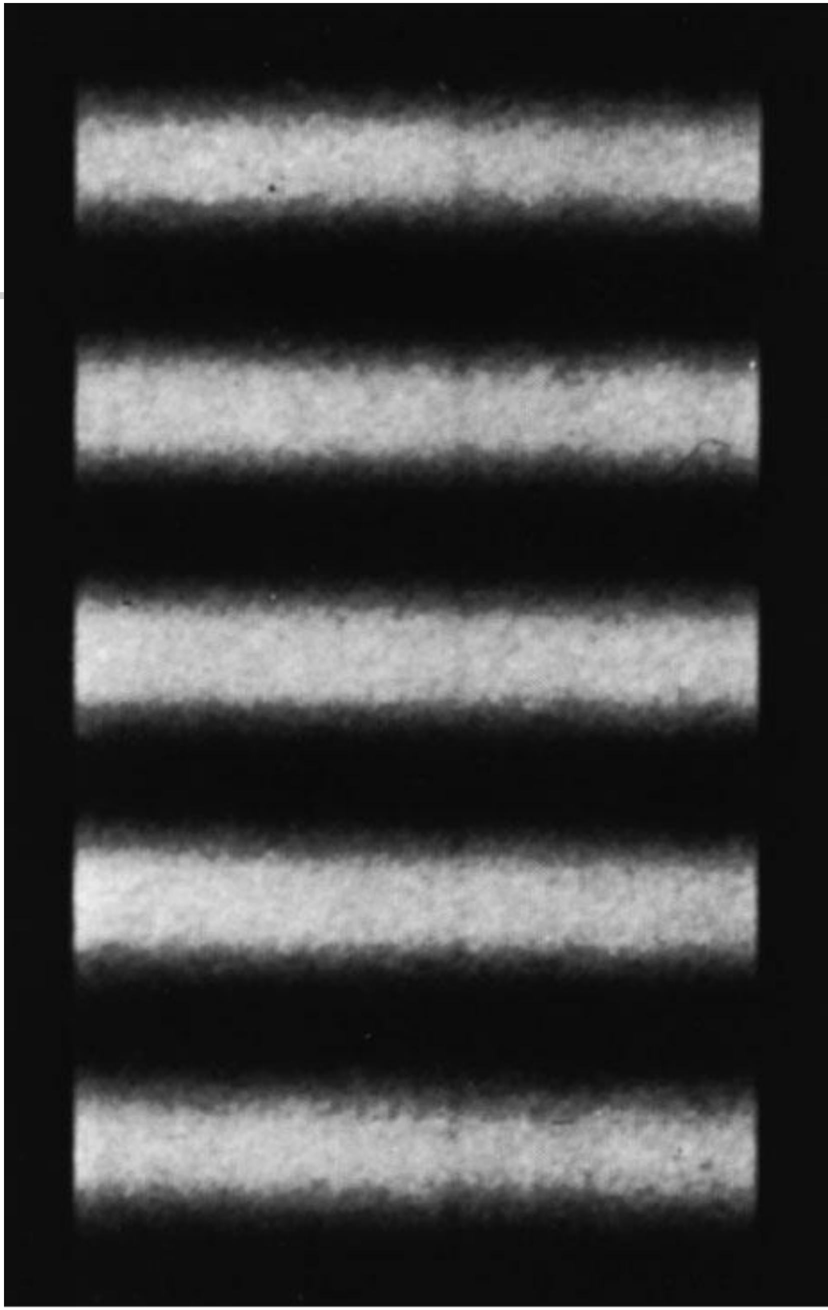


Resulting Interference Pattern

- The light from the two slits form a visible pattern on a screen
- The pattern consists of a series of bright and dark parallel bands called **fringes**
- *Constructive interference* occurs where a bright fringe appears
- *Destructive interference* results in a dark fringe

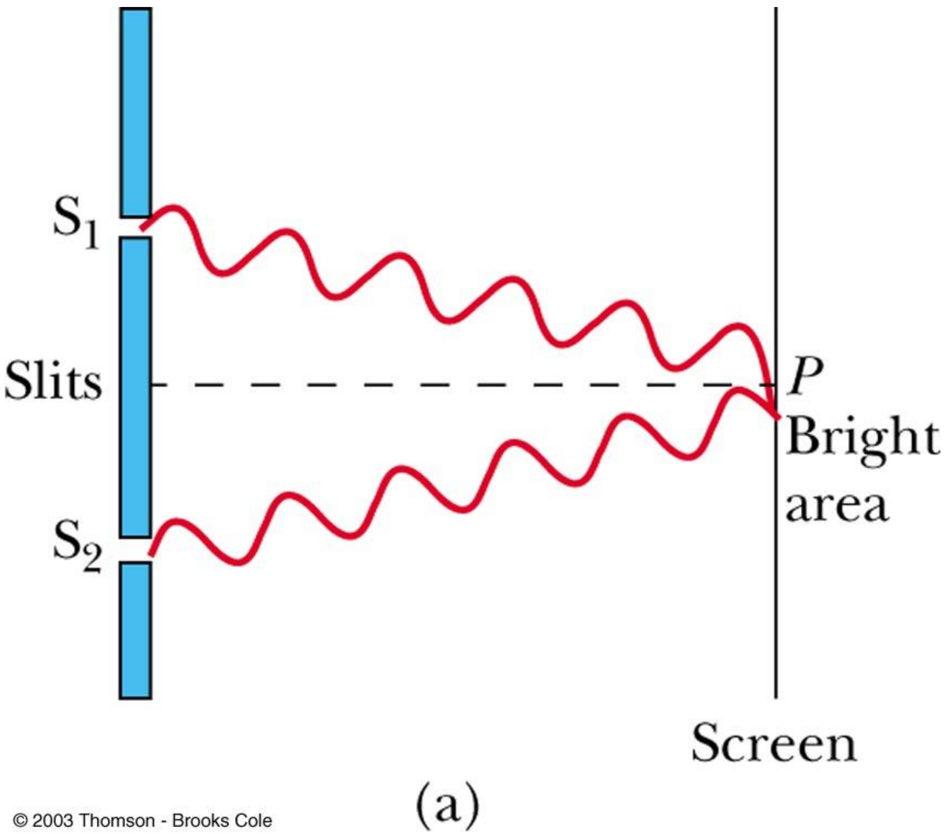
Fringe Pattern

- The fringe pattern formed from a Young's Double Slit Experiment would look like this
- The bright areas represent constructive interference
- The dark areas represent destructive interference



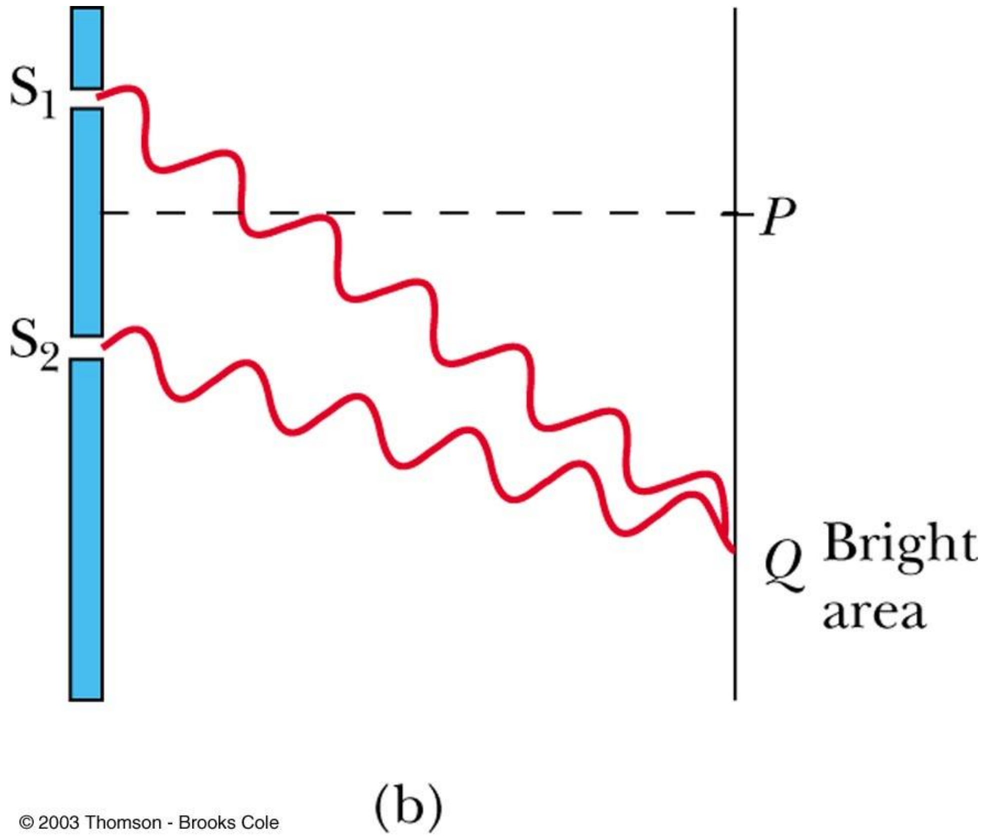
Interference Patterns

- Constructive interference occurs at the center point
- The two waves travel the same distance
  - Therefore, they arrive in phase



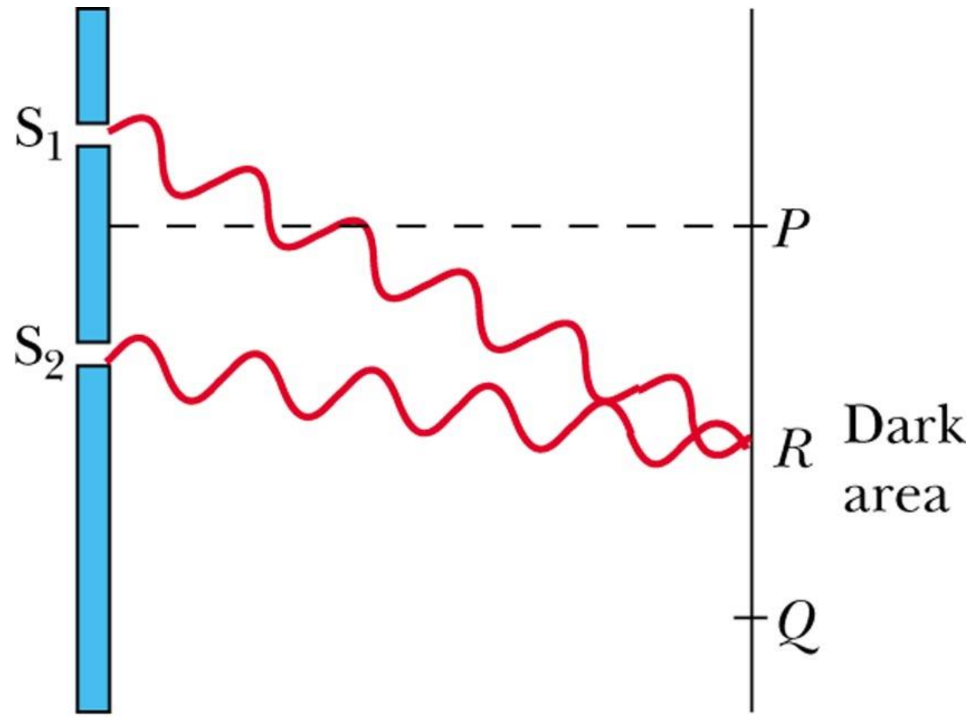
Interference Patterns, 2

- The upper wave has to travel farther than the lower wave
- The upper wave travels one wavelength farther
  - Therefore, the waves arrive in phase
- A bright fringe occurs



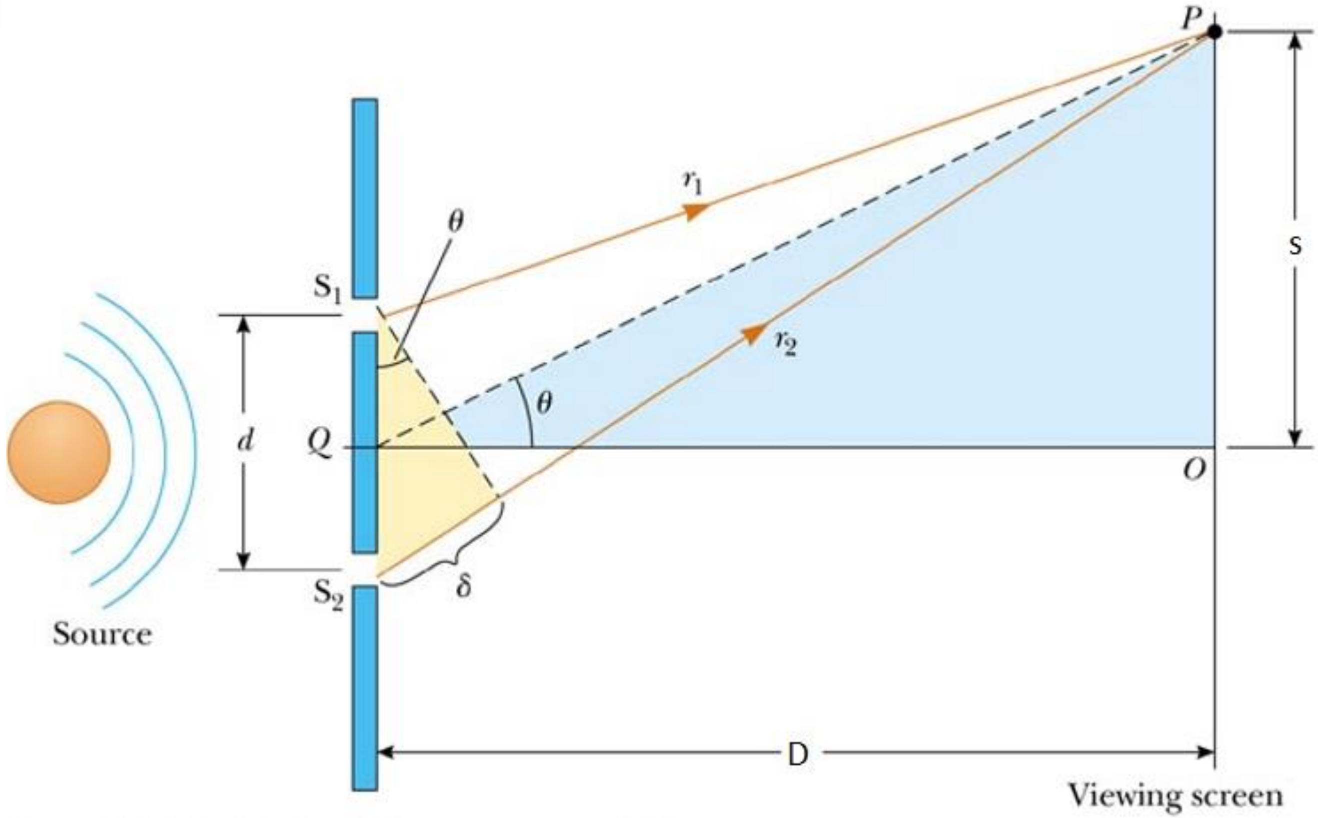
Interference Patterns, 3

- The upper wave travels one-half of a wavelength farther than the lower wave
- The trough of the bottom wave overlaps the crest of the upper wave
- This is destructive interference
  - A dark fringe occurs



(c)

Interference Equation



Separation of successive bright fringes: $s = \frac{\lambda D}{d}$

Interference of Waves

- Waves interfere
  - Constructive interference occurs when the path difference between two waves' motion is zero or some integer multiple of wavelengths
    - path difference = $n\lambda$
  - Destructive interference occurs when the path difference between two waves' motion is an odd half wavelength
    - path difference = $(n + \frac{1}{2})\lambda$