PROPERTIES OF LIGHT

CHAPTER 6

CONTENTS

YOU ARE GOING TO KNOW .....

- Define and explain the concept of wave fronts and rays.
- Explain the law of reflection.
- Explain refraction in terms of Snell's law and the index of refraction.
- Describe internal reflection and give examples of fiber optic application
- Describe diffraction in terms of Huygen's principle.
- Explain Young's experiment

B4 WE START !!!

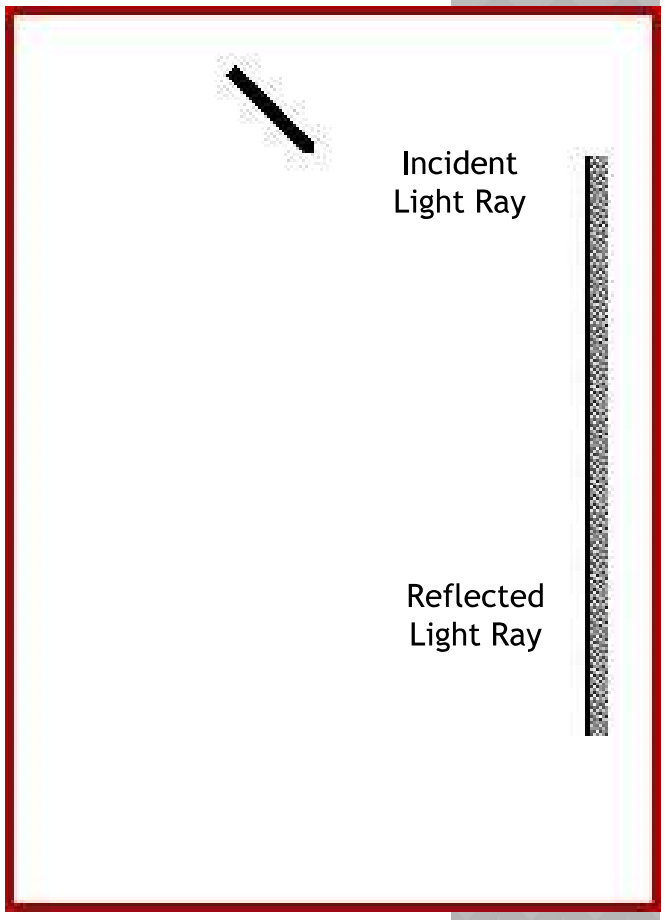
- The study of light has fascinated physicists throughout the ages.
- Newton believed it was a particle
- Young demonstrated that it has wave properties.
- At first we will present a field of study called ray optics.
- This model presents light as traveling in very thin beams called rays...

7.1 REFLECTION OF LIGHT

- This is a reflection from a surface, such as a mirror.
  - The law of reflection stated that the angle of incidence equals to the angle of reflection, for that surface

$$\text{Angle of Incidence} = \text{Angle of Reflection}$$

$$\theta_i = \theta_r$$



**** Remember all angles are measured from the normal, a line that perpendicular to the reflecting surface.**

7.2 REFRACTION OF LIGHT

Part 1: Index of Refraction

- this is an index of the ratio of speed of light in vacuum to speed, v, in a given material

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

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

where c=$3.00 \times 10^{8} ms^{-1}$

7.2 REFRACTION OF LIGHT

- In fact
  - Since light travels more slowly in a material than in vacuum, so, the index of refraction, n, is never less than 1.
  - As light travels from one medium to another, its **frequency** does not change but its **wavelength** does.

- A list of refraction index for difference material

TABLE 22.1 **Indices of Refraction for Various Substances, Measured with Light of Vacuum Wavelength $\lambda_0 = 589$ nm**

Substance	Index of Refraction	Substance	Index of Refraction
Solids at 20°C		**Liquids at 20°C**	
Diamond (C)	2.419	Benzene	1.501
Fluorite (CaF_2)	1.434	Carbon disulfide	1.628
Fused quartz (SiO_2)	1.458	Carbon tetrachloride	1.461
Glass, crown	1.52	Ethyl alcohol	1.361
Glass, flint	1.66	Glycerine	1.473
Ice (H_2O) (at 0°C)	1.309	Water	1.333
Polystyrene	1.49		
Sodium chloride (NaCl)	1.544	**Gases at 0°C, 1 atm**	
Zircon	1.923	Air	1.000 293
		Carbon dioxide	1.000 45

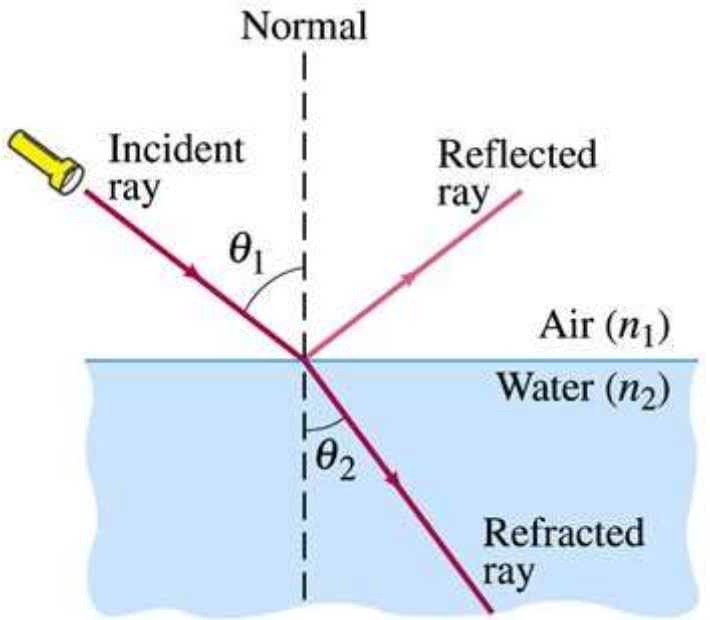
7.2 REFRACTION OF LIGHT

- The speed of light in water is less than that in the air
  - water is said to be optically denser than air
  - The greater the index of refraction of a material, the Greater its optical density, the smaller the speed of light in the material.

7.2 REFRACTION OF LIGHT

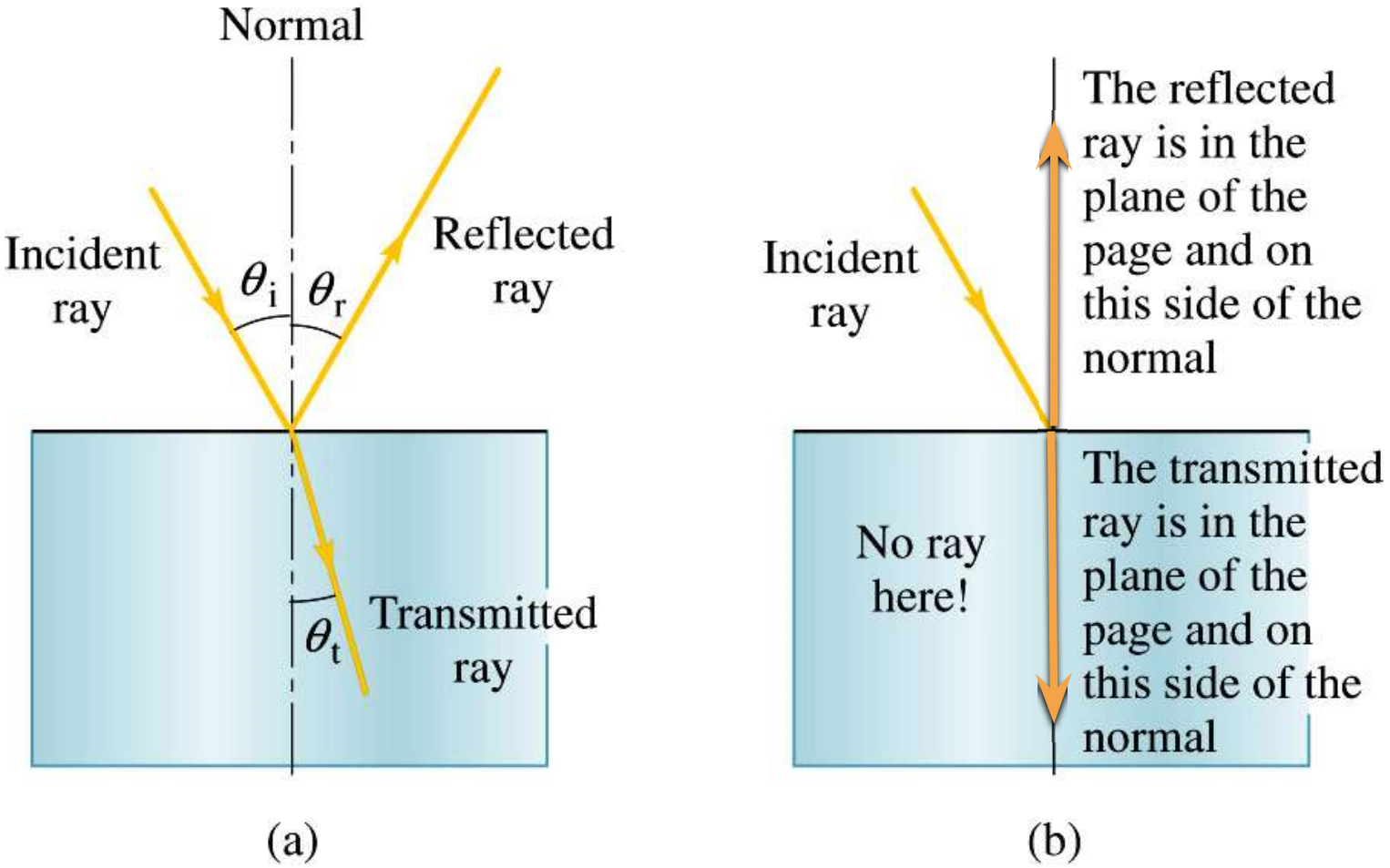
Part 2: Snell's Law

- When a wave is incident on a boundary between transparent medium, Some of its energy is reflected and some is transmitted (refracted).
- The direction in which the transmitted light is propagated is different from the direction of the incident light.
- So the light is said to have been refracted or bent!



****same frequency in all mediums**

7.2 REFRACTION OF LIGHT



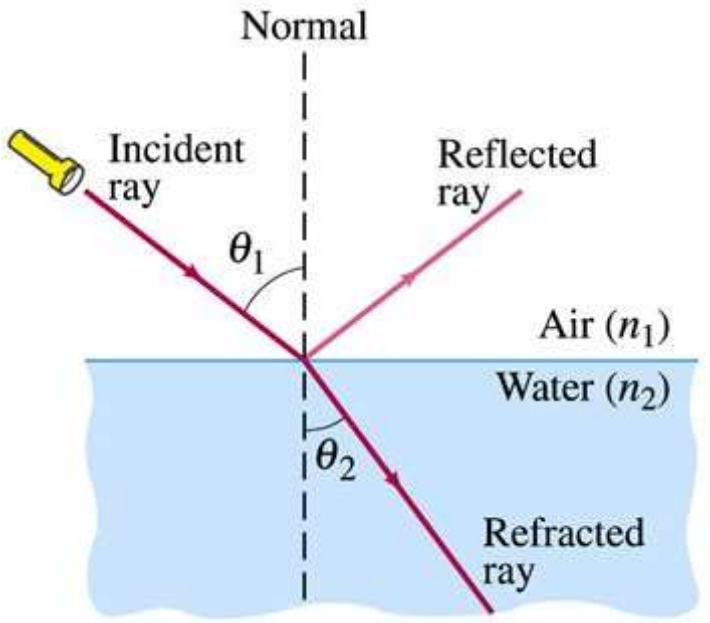
7.2 REFRACTION OF LIGHT

- The angle of refraction, depends on the properties of the two media and on the angle of incidence through relationship:

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

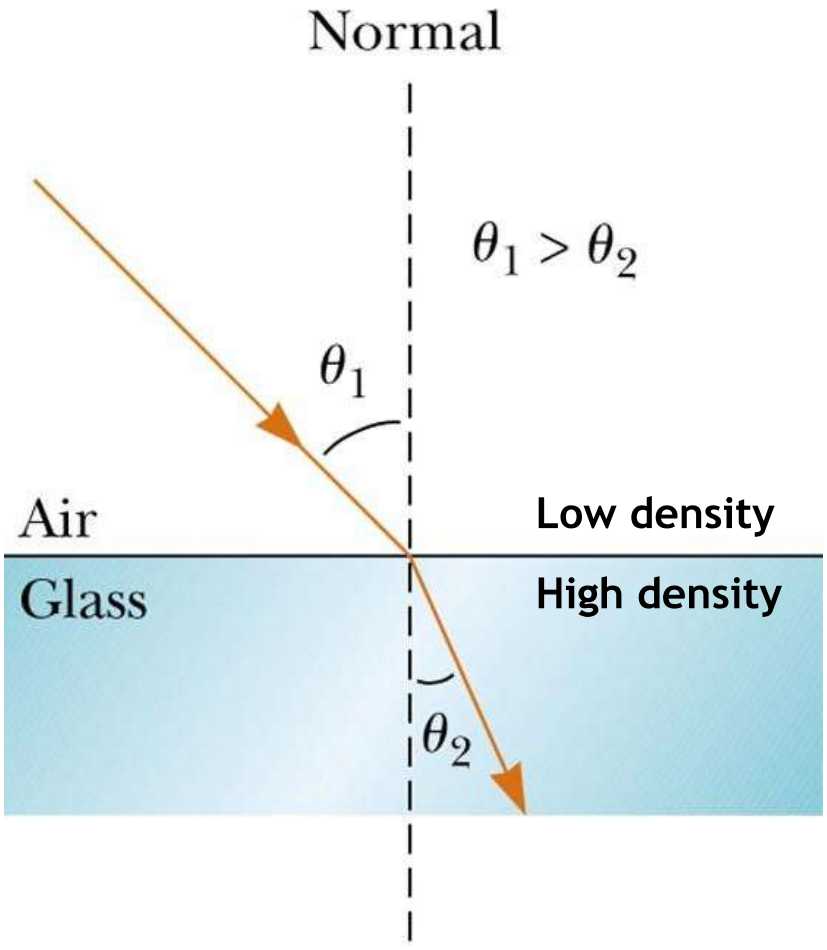
$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

Where θ_1 is the angle of incidence
θ_2 is the angle of refraction.
n is index of refraction



7.2 REFRACTION OF LIGHT

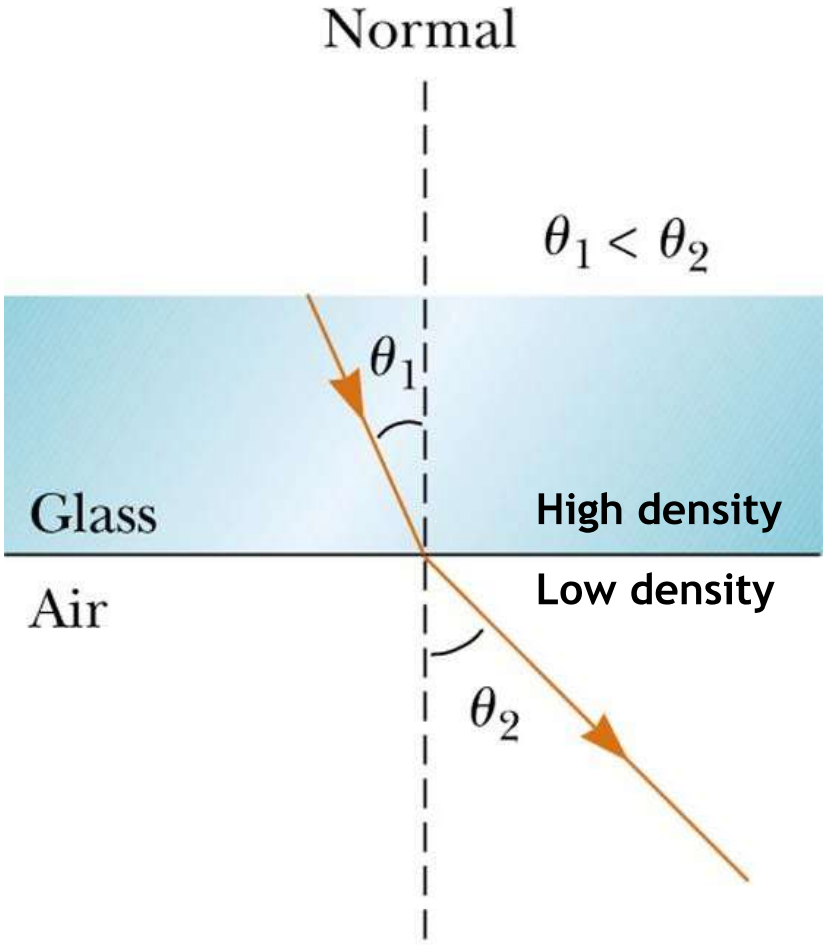
- Light may refract into a material where its speed is lower (index of refraction is higher)
- The angle of refraction is less than the angle of incidence
  - The ray bends *toward* the normal



 (a)

7.2 REFRACTION OF LIGHT

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

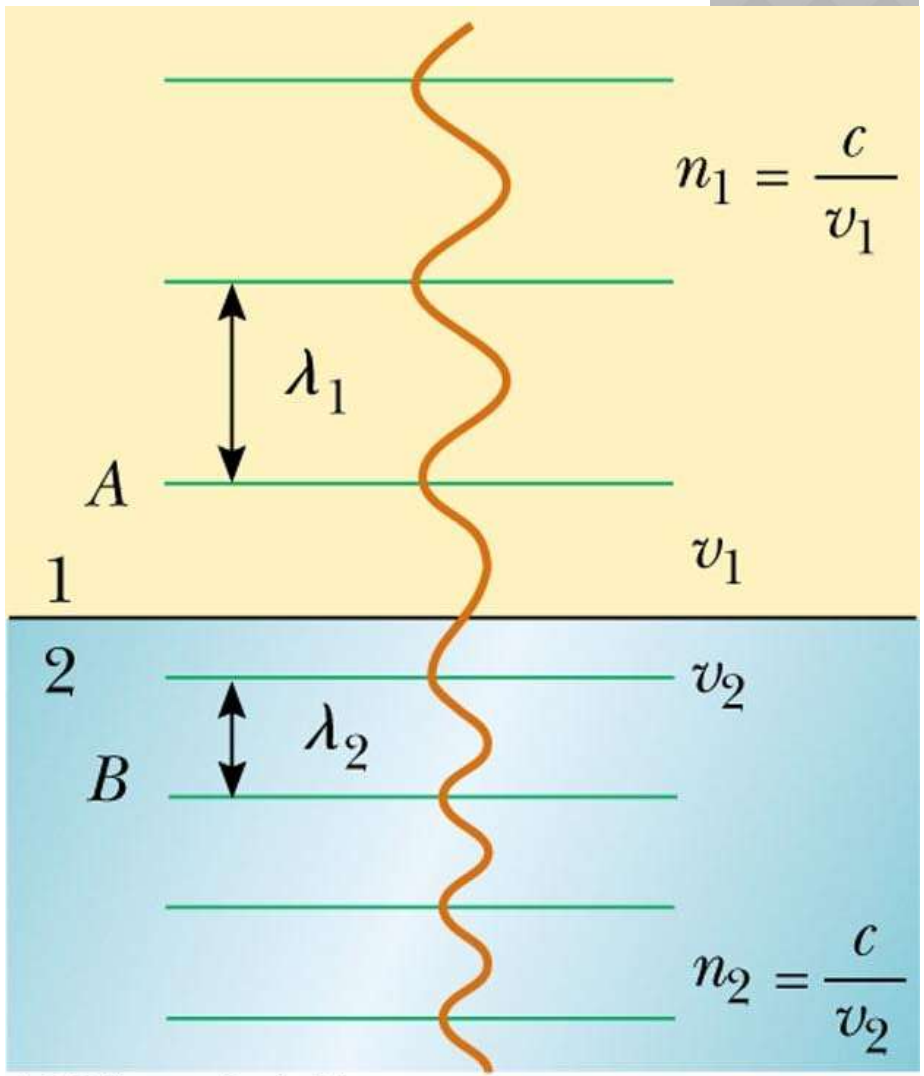


 (b)

7.2 REFRACTION OF LIGHT

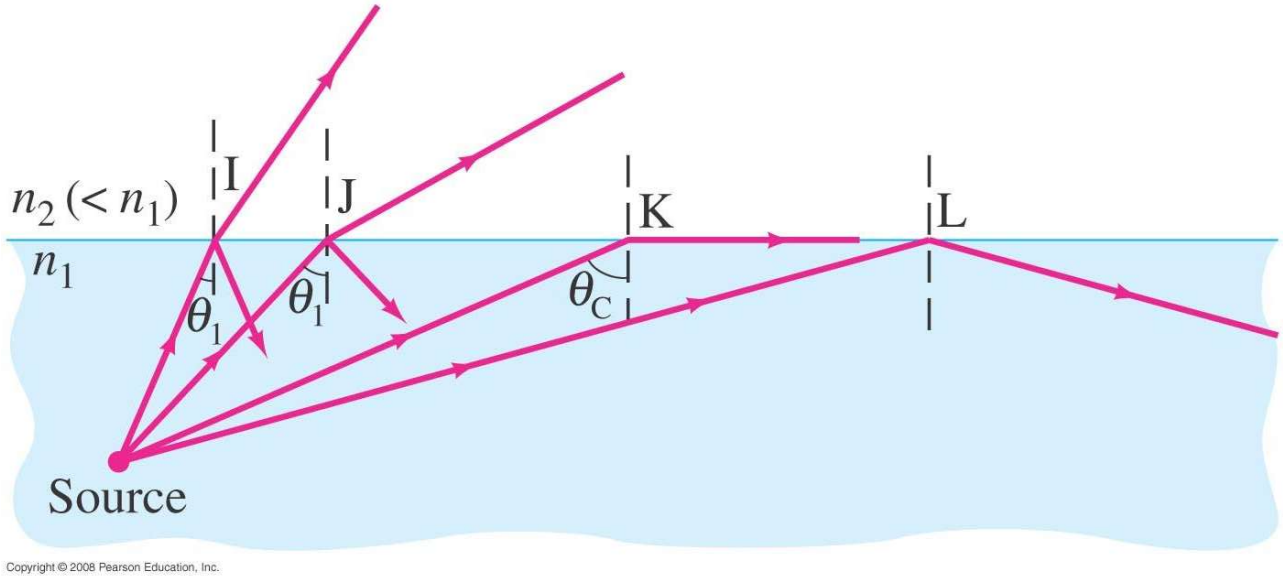
- As light travels from one medium to another, *its frequency does not change*
- Both the wave speed and the wavelength do change
- The ratio of the indices of refraction of the two media can be expressed as various ratios

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



7.2 REFRACTION OF LIGHT

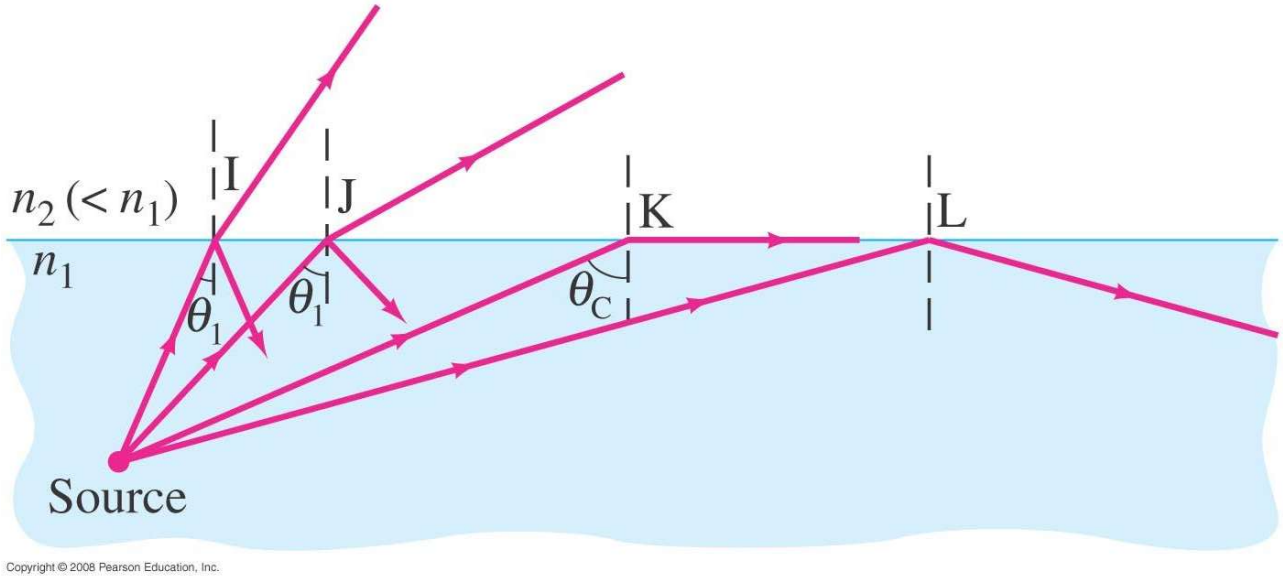
Part 3: Critical Angle



A light passes from one material into a second material where the index of refraction is less, the light bends away from the normal, as in ray I and J.

7.2 REFRACTION OF LIGHT

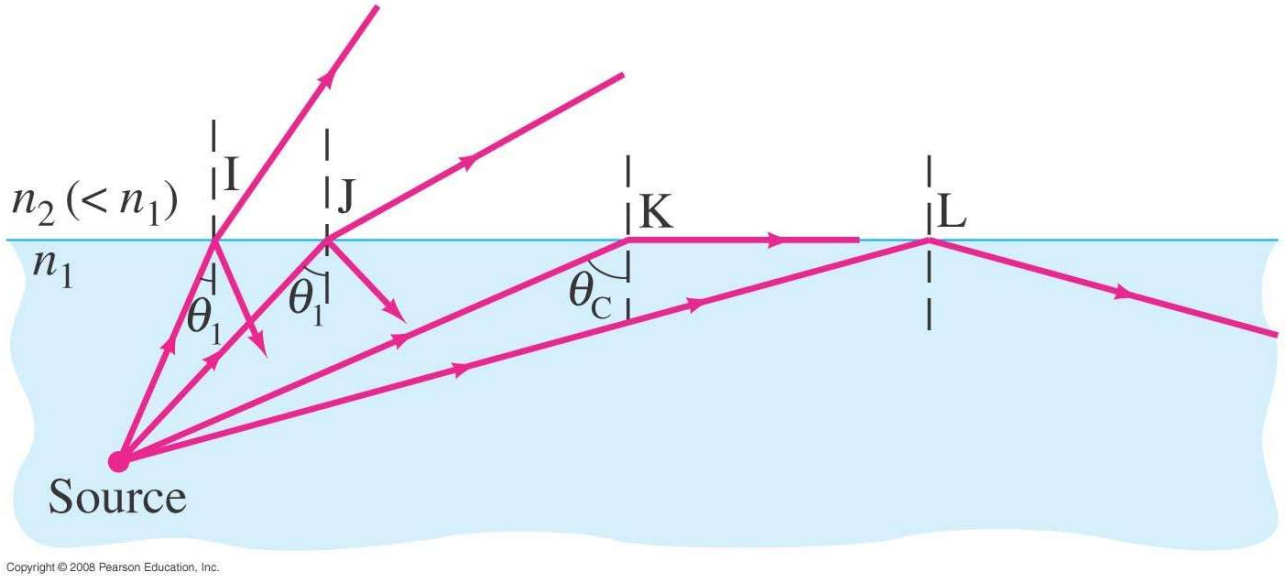
Part 3: Critical Angle



At a particular angle, the angle of reflection will be 90º .
The refracted ray would skim the surface, as in ray k.

We call this angle as critical angle, θ_C

Part 3: Critical Angle



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

$$\frac{\sin\theta_1}{\sin 90} = \frac{n_2}{n_1}$$

$$\sin\theta_1 = \frac{n_2}{n_1}\sin 90^o$$

$$\sin\theta_C = \frac{n_2}{n_1}$$

$$\theta_C = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

** $n2 < n1$

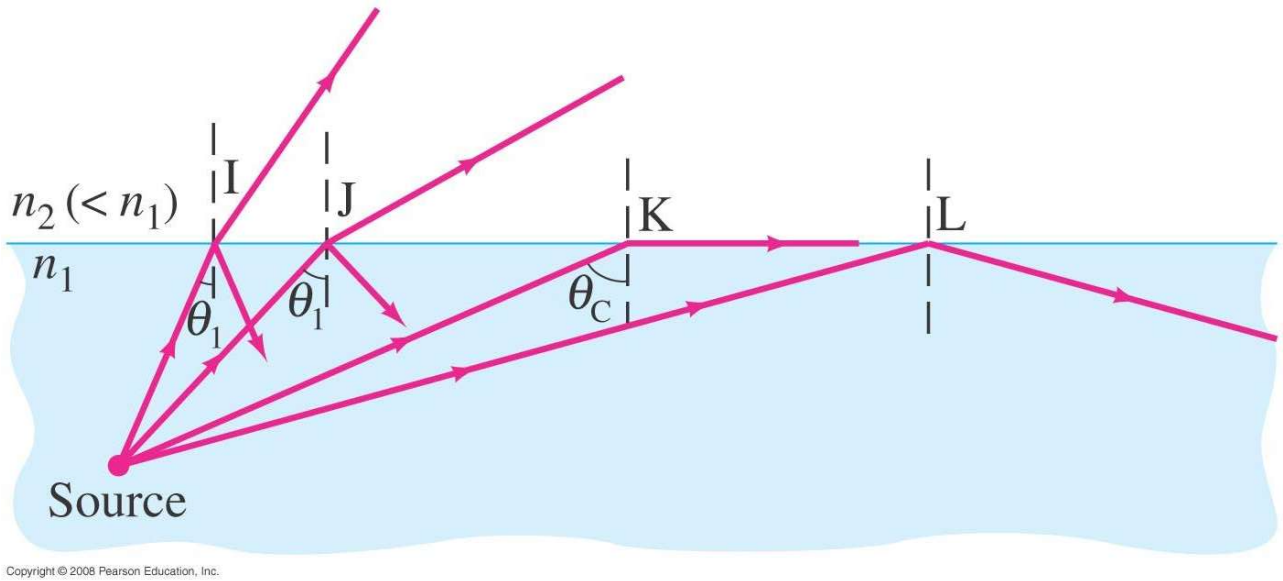
7.2 REFRACTION OF LIGHT

Question ?

How to produce critical angle ?

- Increased the incidence angle when we reflect the ray

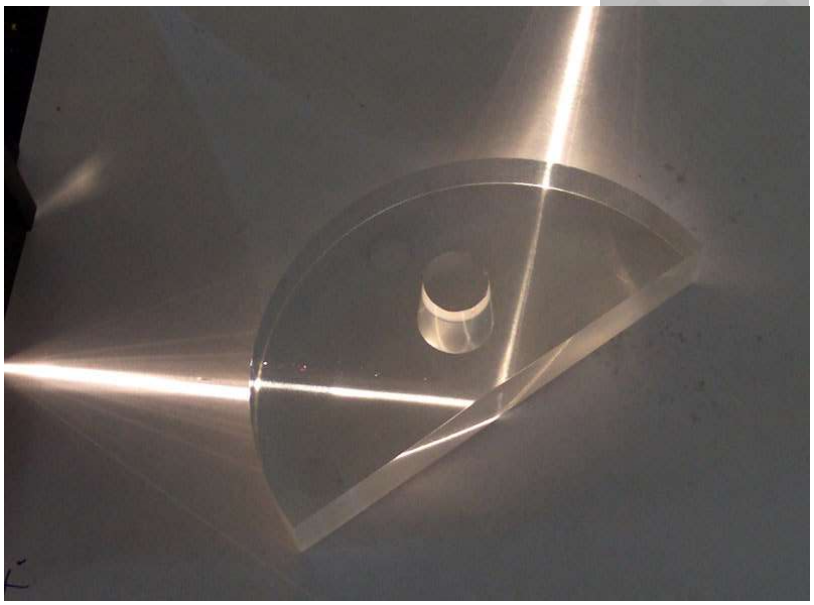
7.2 REFRACTION OF LIGHT



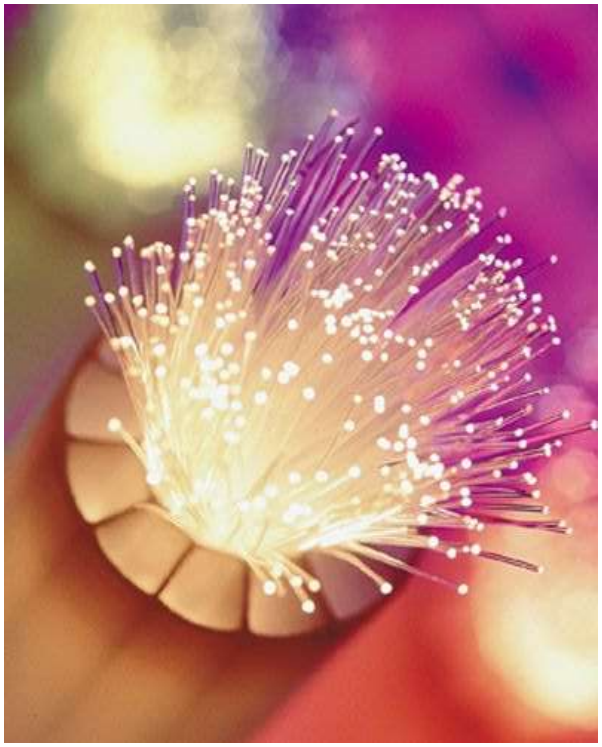
- For any incident angle less than θ_c (Case I and J)
  - Refracted ray
  - Reflected ray
- For any incident angle equal θ_c
  - Ray would skim the surface
- For any incident angle grater than θ_c.
  - Total internal reflection

Part 4: Total Internal Reflection

- *It is an effect occurs only when light attempts to move from a medium of given index of refraction to a medium of lower index of refraction and the incidence angle is equal or greater than the critical angle of the higher refractive index medium.*



- Application of total internal reflection
  - Fiber optic
  - binoculars



7.2 REFRACTION OF LIGHT

Example

- A beam of light in air enters

  a.) water (n = 1.33)

  b.) glass (n = 1.50)

  at an angle of 60 degree relative to the normal. Find the angle of refraction for each case.

- Solution

a)

medium 1: air

medium 2: water

$$
\begin{aligned}
{}_1n_2 &= \frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2} \\
\frac{1.33}{1.00} &= \frac{\sin 60^o}{\sin\theta_{water}} \\
\sin\theta_{water} &= \frac{\sin 60^o}{1.33}(1.00) \\
&= 0.6511 \\
\theta_{water} &= 40.6^o
\end{aligned}
$$

- Solution

b)

medium 1: air

medium 2: glass

$$
\begin{aligned}
{}_1n_2 &= \frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2} \\
\frac{1.50}{1.00} &= \frac{\sin 60^o}{\sin\theta_{glass}} \\
\sin\theta_{glass} &= \frac{\sin 60^o}{1.50}(1.00) \\
&= 0.5774 \\
\theta_{glass} &= 35.3^o
\end{aligned}
$$

- Example

The refractive index of diamond is 2.42. What is the critical angle for light passing from diamond to air?

- Solution

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

$$n_{diamond} \sin\theta_c = n_{air} \sin 90^o$$

$$2.42 \sin\theta_c = 1(1)$$

$$\sin\theta_c = \frac{1}{2.42} = 0.4132$$

$$\theta_c = 24.4^o$$

- Example

What is the critical angle for light passing from glass (n=1.54) to water (n=1.33)

Solution

$$n_{glass}\sin\theta_{glass} = n_{water}\sin\theta_{water}$$

$$1.54\sin\theta_c = 1.33\sin 90^o$$

$$1.54\sin\theta_c = 1.33(1)$$

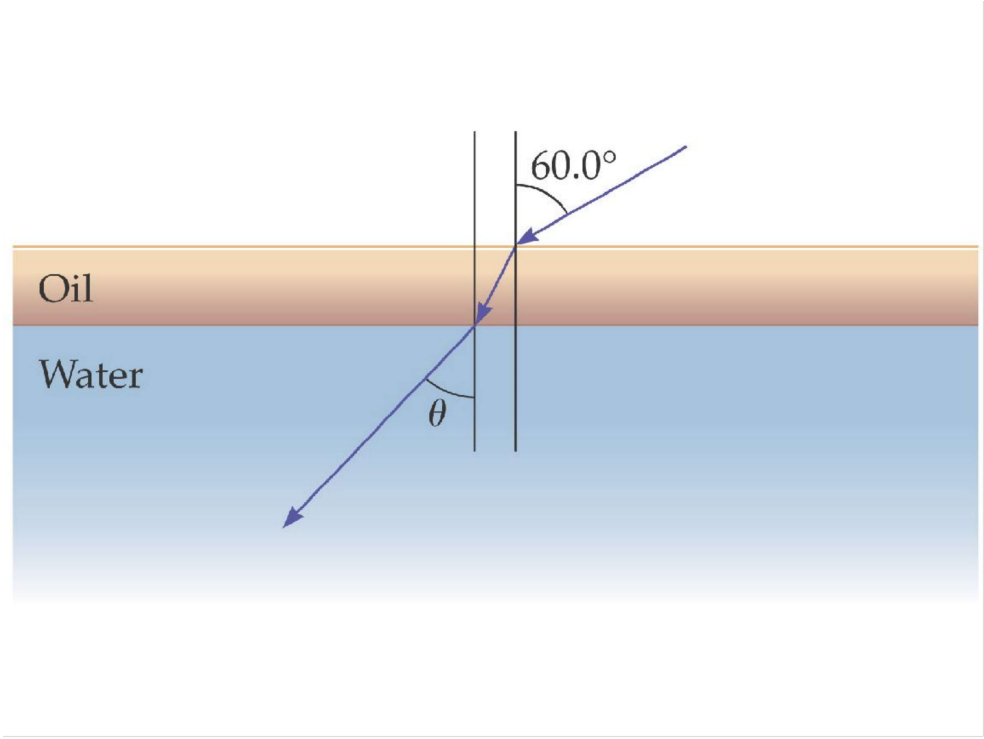
$$\sin\theta_c = \frac{1.33}{1.54} = 0.8636$$

$$\theta_c = 59.7^o$$

7.2 REFRACTION OF LIGHT

- Example

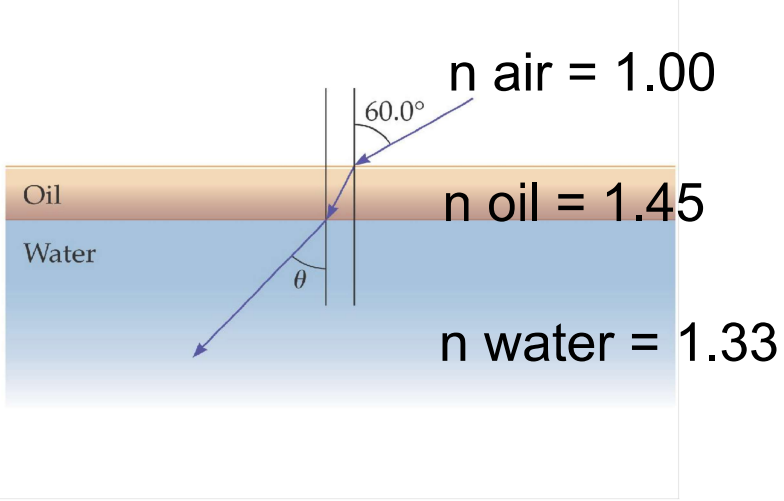
A layer of oil (n=1.45) floats on water (n=1.33) A ray of light shines onto the oil with an incidence angle of 60º. Find the angle the ray makes in the water.



- Solution

Between medium air and oil

$$n_{air}\sin\theta_{air} = n_{oil}\sin\theta_{oil}$$
$$1.0\sin 60^o = 1.45\sin\theta_{oil}$$
$$\sin\theta_{oil} = \frac{\sin 60^o}{1.45}$$
$$= 0.5973$$
$$\theta_{oil} = 36.7^o$$



Between medium oil and water

$$n_{oil}\sin\theta_{oil} = n_{water}\sin\theta_{water}$$
$$1.45\sin 36.7^o = 1.33\sin\theta_{water}$$
$$\sin\theta_{water} = \frac{(1.45)\sin 36.7^o}{1.33}$$
$$= 0.6515$$
$$\theta_{oil} = 40.7^o$$

7.2 REFRACTION OF LIGHT

- Example

A diamond in air is illuminated with white light . On one particular facet, the angle of incidence is 26°.Inside the diamond, red light (λ=660 nm in vacuum) is refracted at 10.48° with respect to the normal; Blue light (λ=470 nm in vacuum) is refracted at 10.33°

a) What are the indices of refraction for red and blue light in diamond?

b) What is the ratio of the speed of red light to the speed of blue light in diamond?

- Solution

a) What are the indices of refraction for red and blue light in diamond?

$$n_{air}\sin\theta_{air} = n_d \sin\theta_d$$

$$n_d = n_{air}\frac{\sin\theta_d}{\sin\theta_{air}}$$

For Red:

$$n_{red} = n_{air}\frac{\sin 26^o}{\sin 10.48}$$

$$= 2.410$$

For Blue:

$$n_{blue} = n_{air}\frac{\sin 26^o}{\sin 10.33}$$

$$= 2.445$$

b) What is the ratio of the speed of red light to the speed of blue light in diamond?

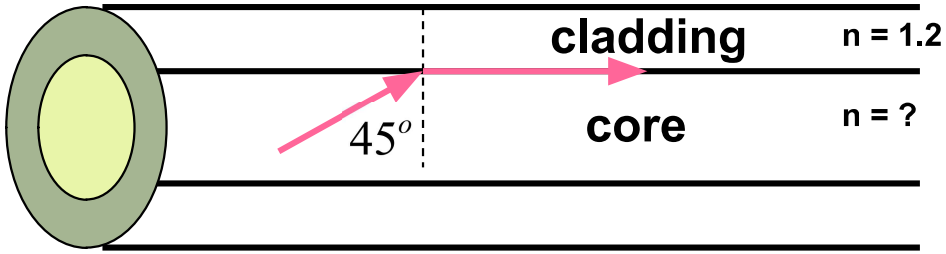
$$n = \frac{c}{v}$$

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

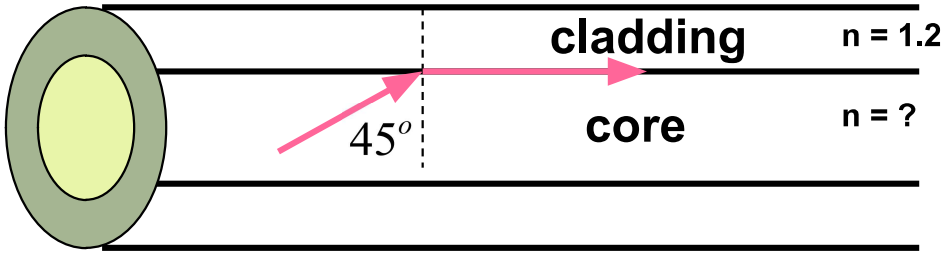
$$\frac{v_{red}}{v_{blue}} = \frac{\frac{c}{n_{red}}}{\frac{c}{n_{blue}}} = \frac{n_{blue}}{n_{red}} = \frac{2.445}{2.410} = 1.0145$$

- Example

What is the index of incidence of the core of an optical fiber if the cladding has n=1.20 and the critical angle at the core cladding boundary is 45°



- Solution



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

$$n_1 \sin\theta_c = n_2 \sin 90^o$$

$$n_1 = \frac{n_2}{\sin\theta_c}$$

$$= \frac{1.2}{\sin 45^o}$$

$$= 1.70$$

7.3 HUYGEN'S PRINCIPLE AND DIFFRACTION

Light is a form of wave motion rather than a stream of particles

HUYGEN'S PRINCIPLE

- A geometric construction for determining the position of a new wave at some point based on the knowledge of the wave front that preceded it

7.3 HUYGEN'S PRINCIPLE AND DIFFRACTION

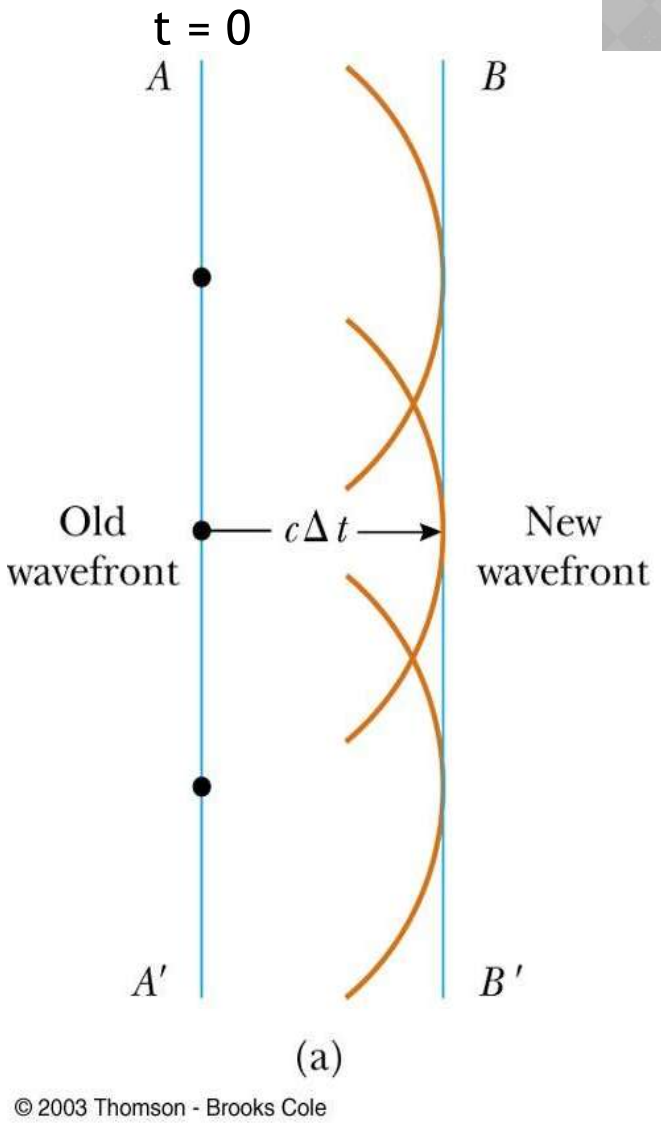
- Every point of a wave front may be considered the source of secondary wavelets that spread out in all directions with a speed equal to the speed of propagation of the waves.

- All points on a given wave front are taken as point sources for the production of spherical secondary waves, called wavelets, which propagate in the forward direction with speeds characteristic of waves in that medium
  - After some time has elapsed, the new position of the wave front *is the surface tangent to the wavelets*

7.3 HUYGEN'S PRINCIPLE AND DIFFRACTION

Huygen's Construction for a Plane Wave

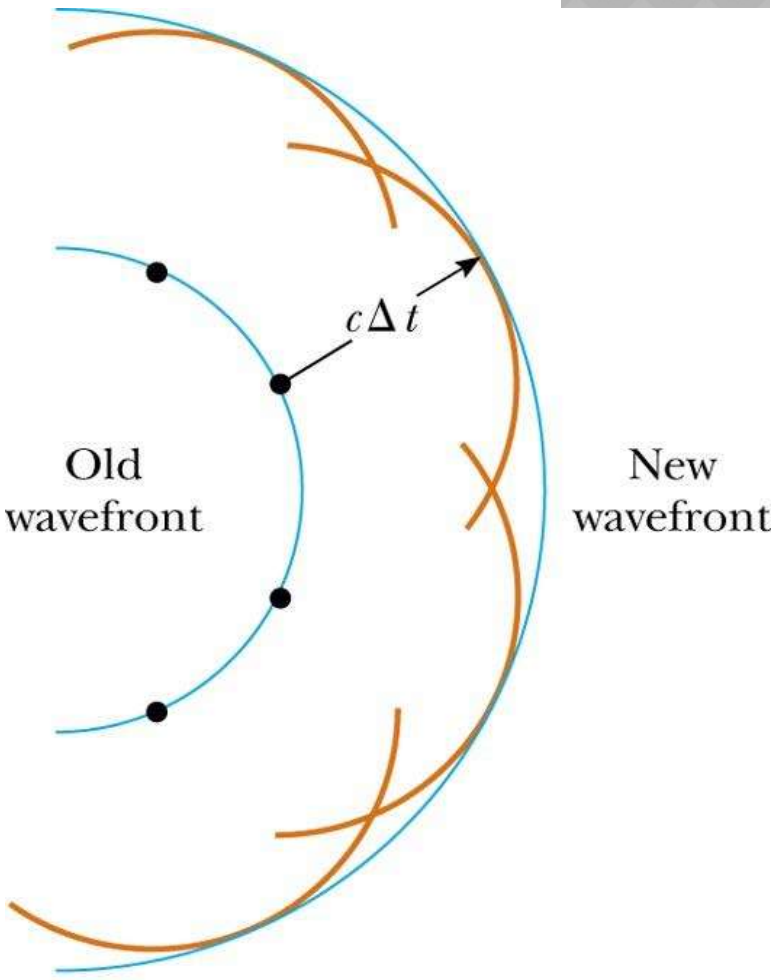
- At $t = 0$, the wave front is indicated by the plane AA'
- The points are representative sources for the wavelets
- After the wavelets have moved a distance $c\Delta t$, a new plane BB' can be drawn tangent to the wave-fronts



7.3 HUYGEN'S PRINCIPLE AND DIFFRACTION

Huygen's Construction for a spherical Wave

- The inner arc represents part of the spherical wave
- The points are representative points where wavelets are propagated
- The new wave-front is tangent at each point to the wavelet



(b)

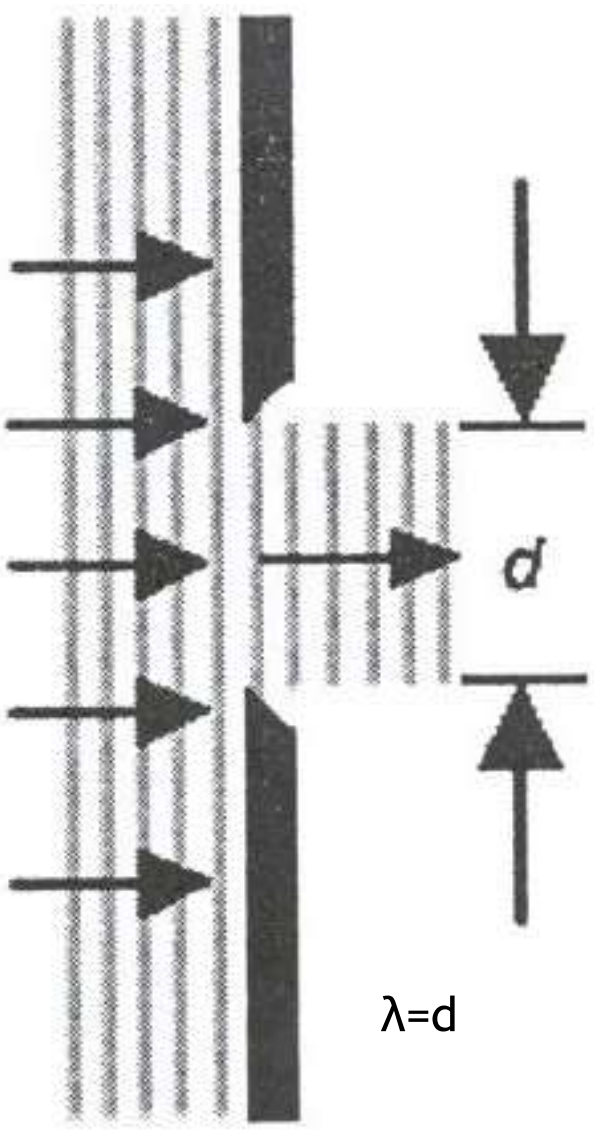
7.3 HUYGEN'S PRINCIPLE AND DIFFRACTION

Diffraction

- Huygen's principle requires that the 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 wave pass through small openings, around obstacles or by sharp edges

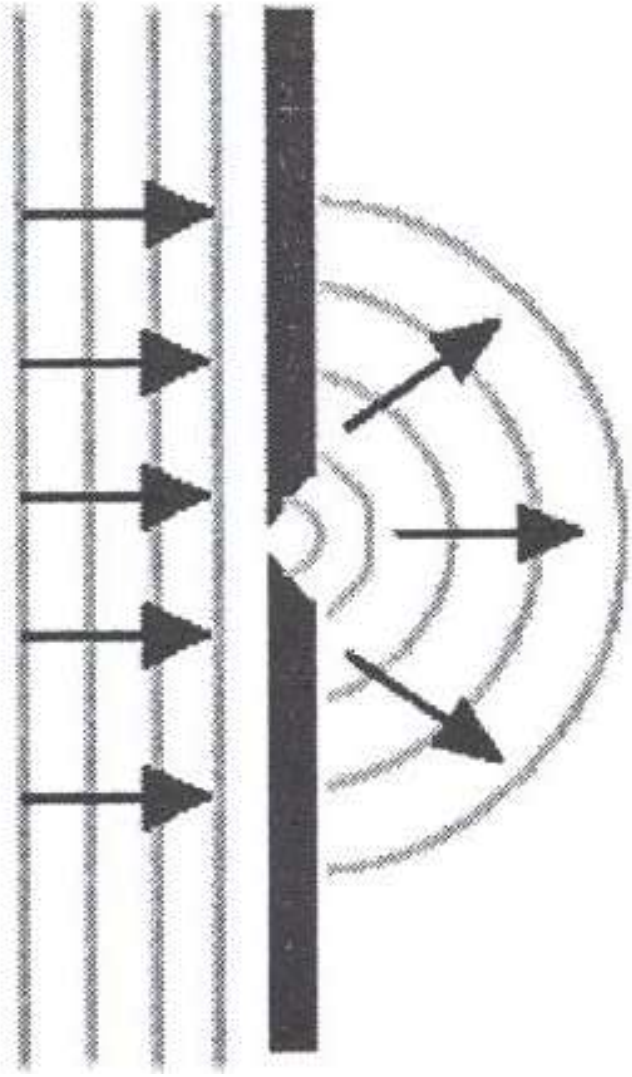
7.3 HUYGEN'S PRINCIPLE AND DIFFRACTION

- If the wave meets a barrier in which there is a circular opening whose diameter is large relative to the wavelength (λ)
  - The wave emerging from the opening continues to move in a straight line



7.3 HUYGEN'S PRINCIPLE AND DIFFRACTION

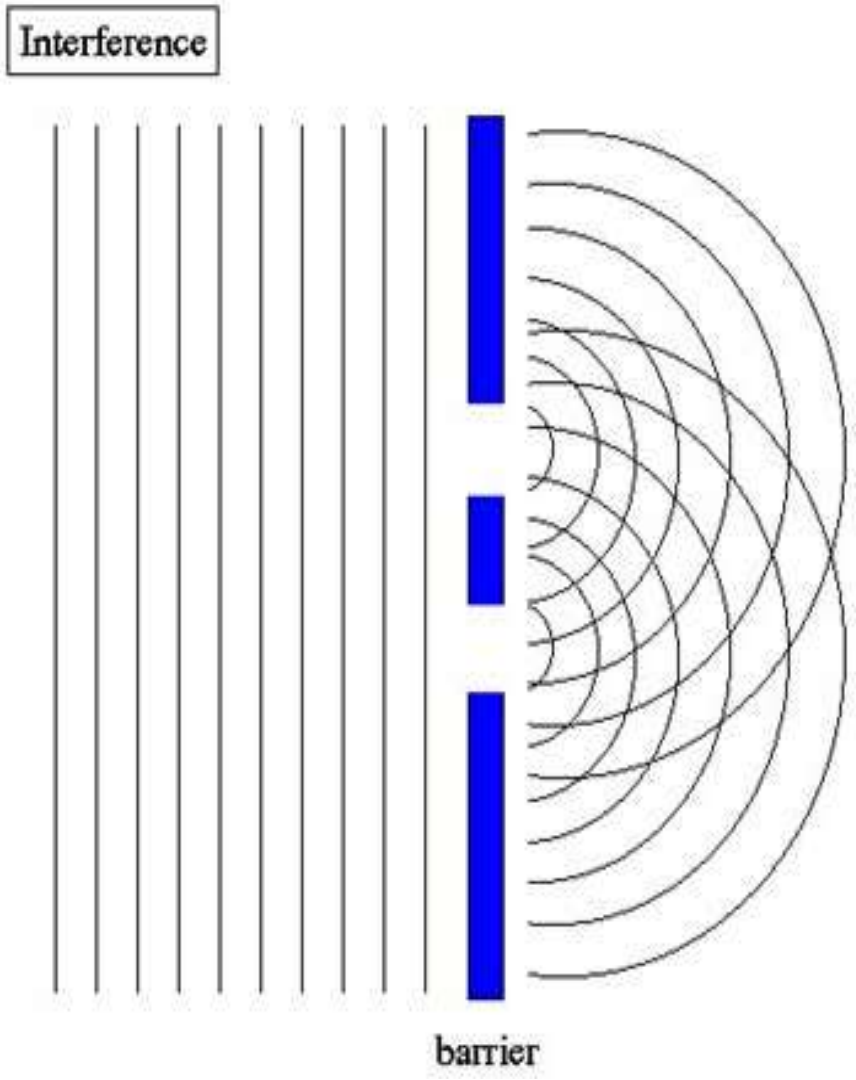
- If the opening is relative small than the wave-length



7.4 INTERFERENCE

Interference

- It is associated with light waves arises when the electromagnetic fields that constitute the individual waves combine.

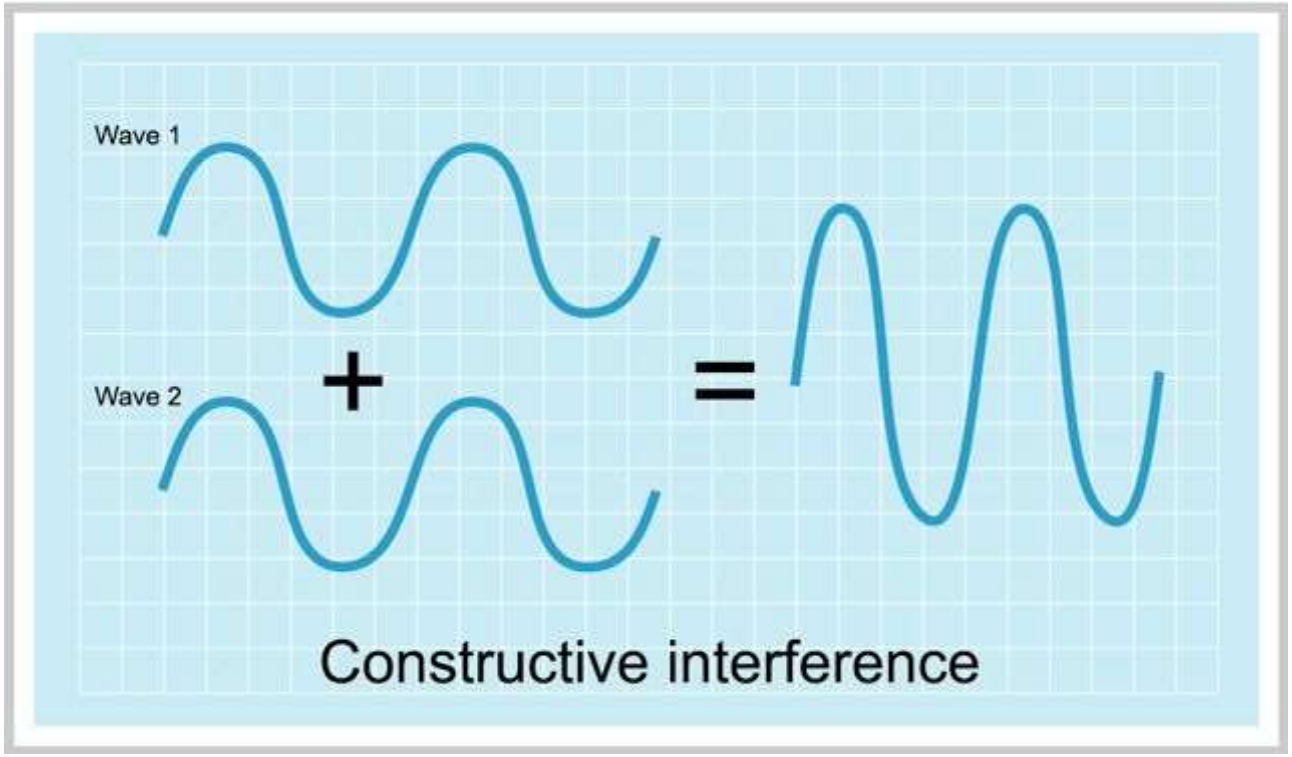


7.4 INTERFERENCE

- Interference will happen if
  - The source must be monochromatic
    - Single wavelength
    - Colors are all the colors (tints, tones and shades) of a single hue
  - The source must coherent (in phase)
    - They must maintain a constant phase with respect to each other.
  - The superposition principle must apply
    - A linear system

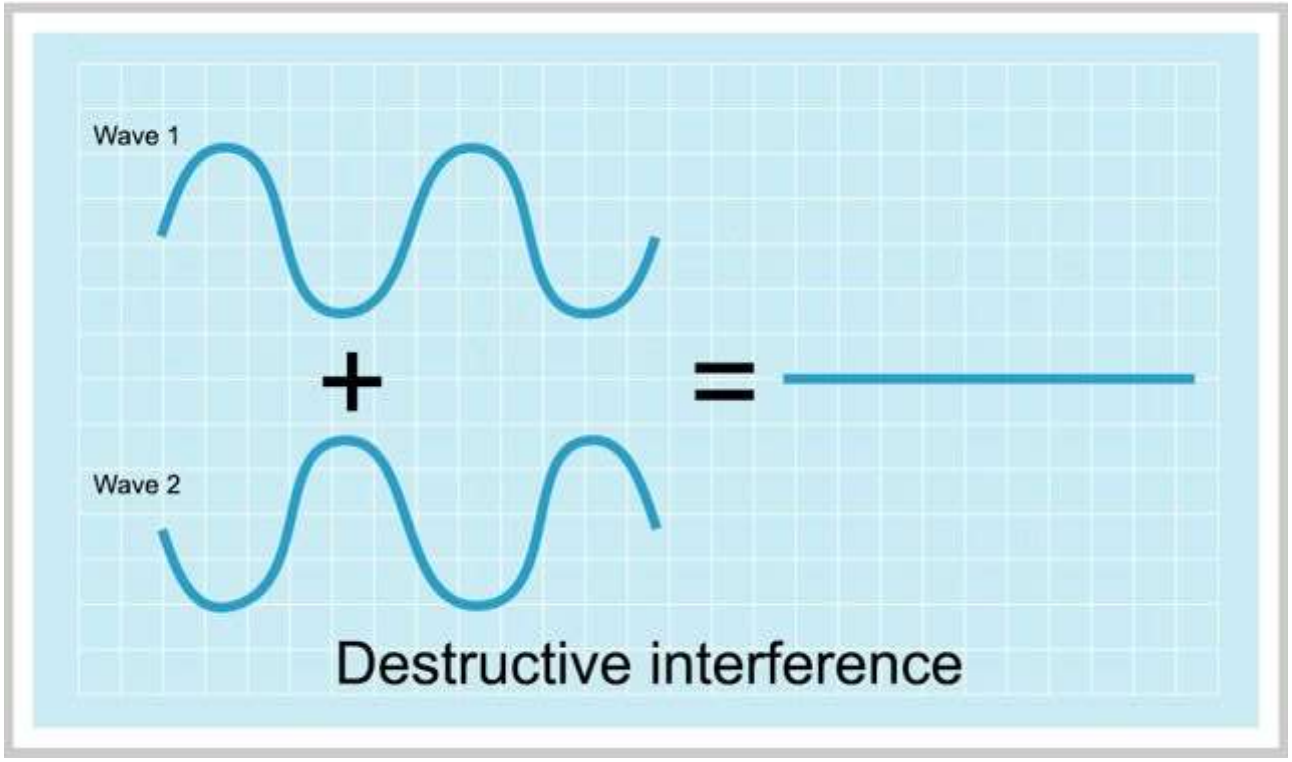
7.4 INTERFERENCE

- superposition principle
  - Constructive interference



7.4 INTERFERENCE

- superposition principle
  - Destructive Interference

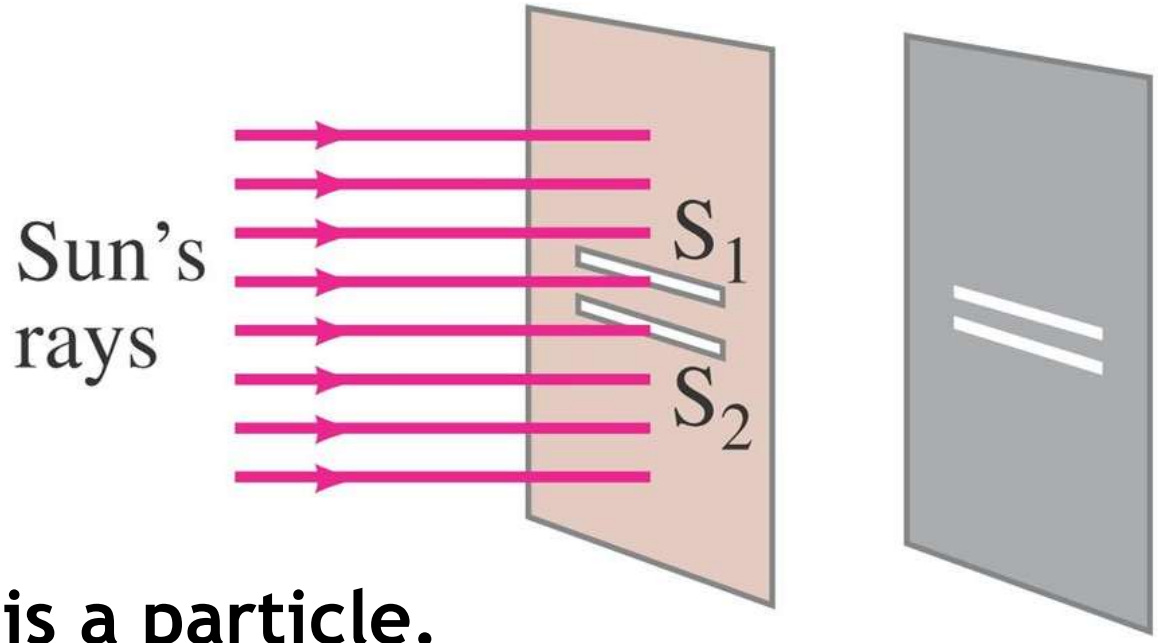


7.4 INTERFERENCE

- Young's Double-Slit Experiment
  - Thomas Young obtained convincing evidence for the wave nature light and was able to measure wavelengths for visible light

7.4 INTERFERENCE

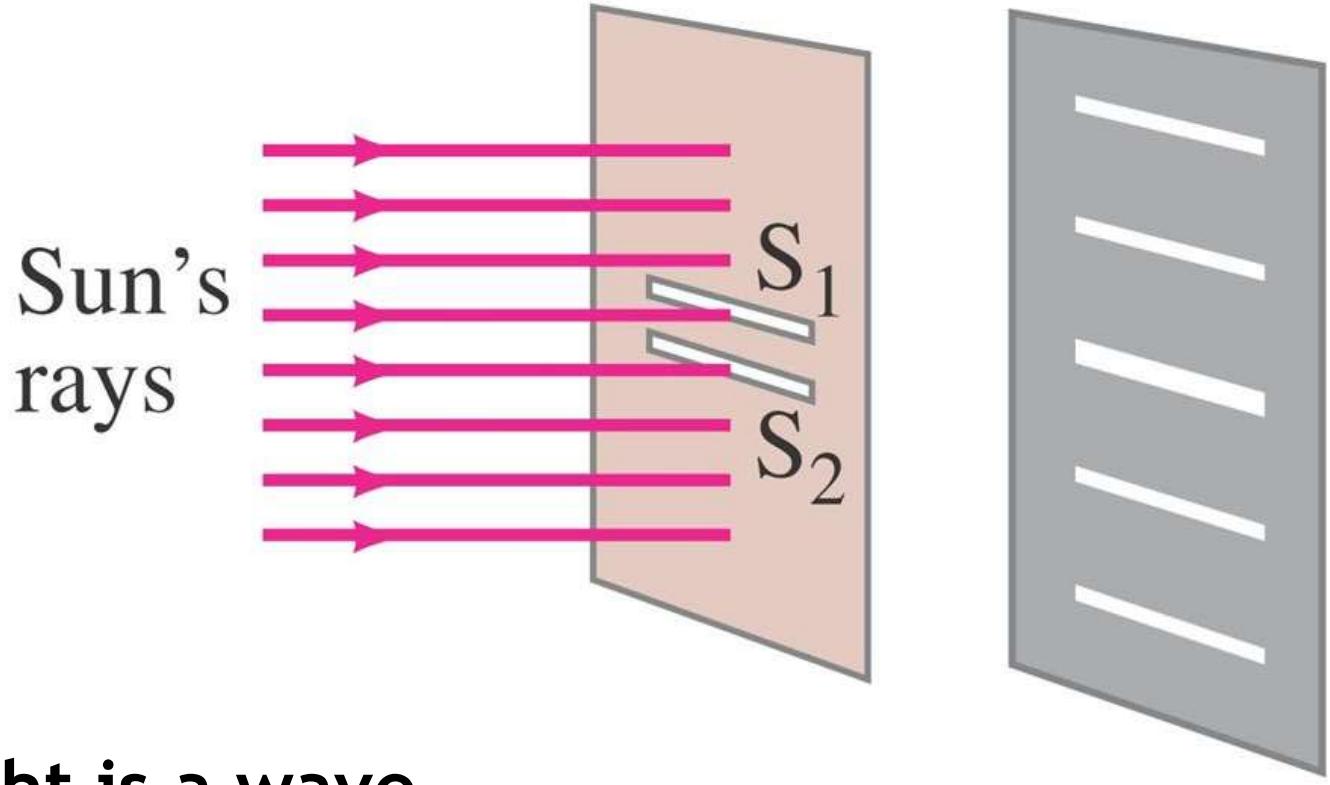
- Young's said that
  - If light consists of tiny particles, we might expect to see two bright lines on a screen placed behind the slits.



Light is a particle.

7.4 INTERFERENCE

- In fact, what we can see is **a series of bright lines**

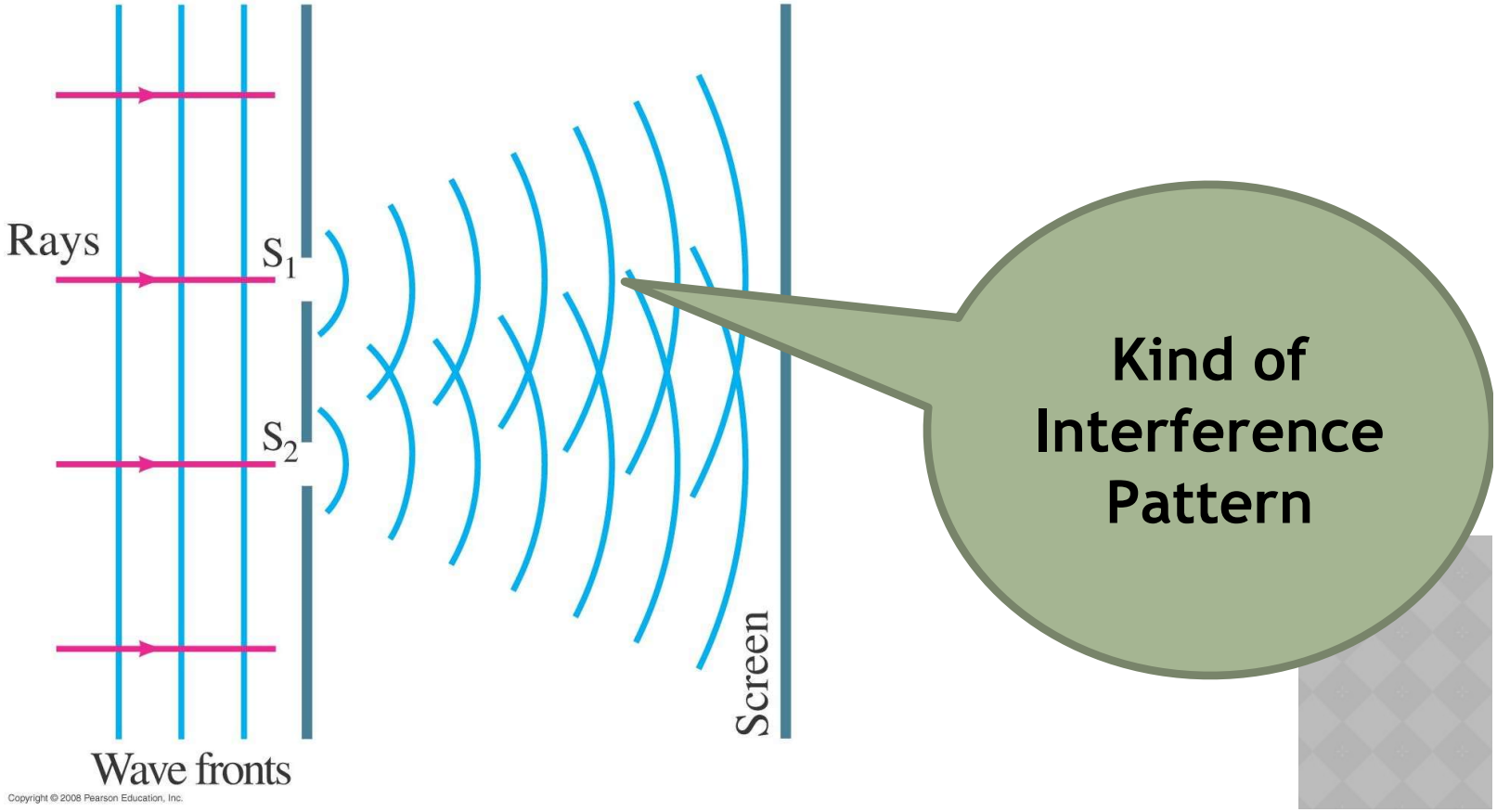


Light is a wave.

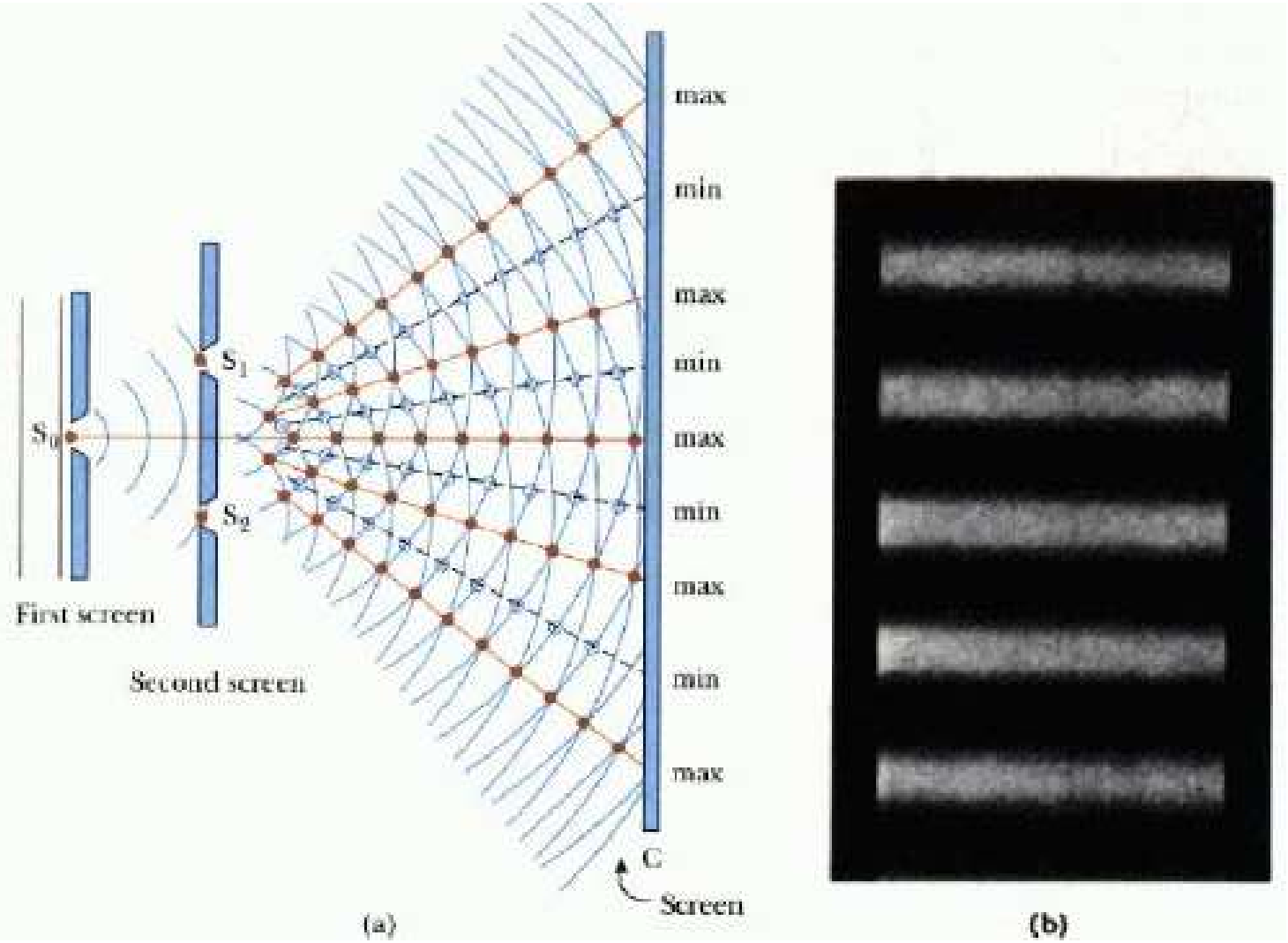
7.4 INTERFERENCE

- What Happen ???

- Explanation
  - Consider that we are using a single wavelength falling on the 2 slits, S_1 and S_2
  - Because of diffraction, the waves leaving 2 small slits spread out.

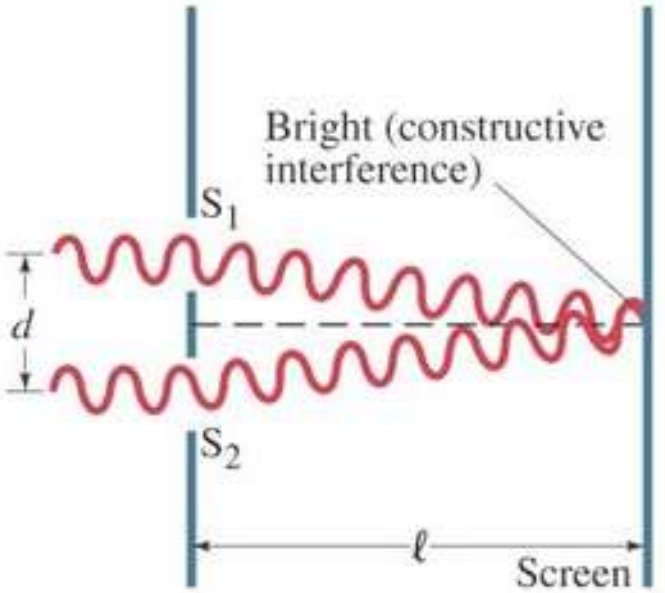


7.4 INTERFERENCE



7.4 INTERFERENCE

- Waves of wavelength λ are entering S_1 and S_2, which are a distance d apart.
- The waves spread out in all direction after passing through the slits.
- In this diagram, the waves reaching the center of the screen (θ=0º)
- The waves are travel the same distance, so they are in phase
  - Crest of one wave arrives at the same time as crest of the other wave
  - Amplitudes of the 2 waves add to form a large amplitude wave
    - Constructive Interference



(a) $\theta = 0^\circ$

7.4 INTERFERENCE

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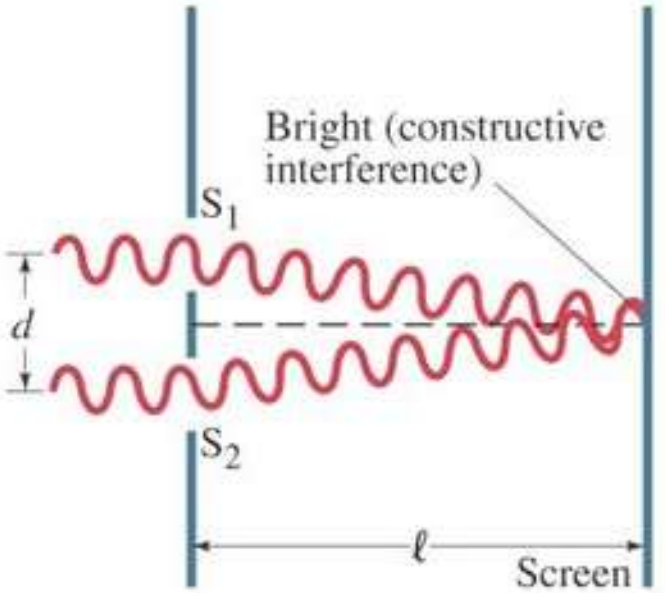
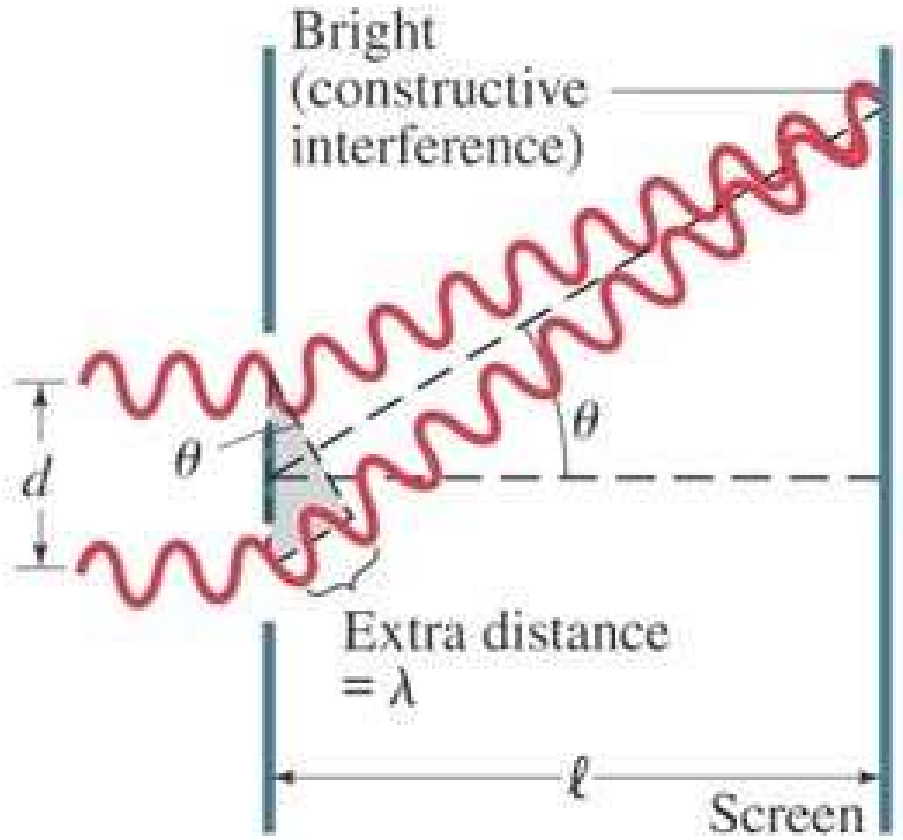
  - Amplitudes of the 2 waves add to form a large amplitude wave
    - Constructive Interference



(a) θ = 0º

7.4 INTERFERENCE

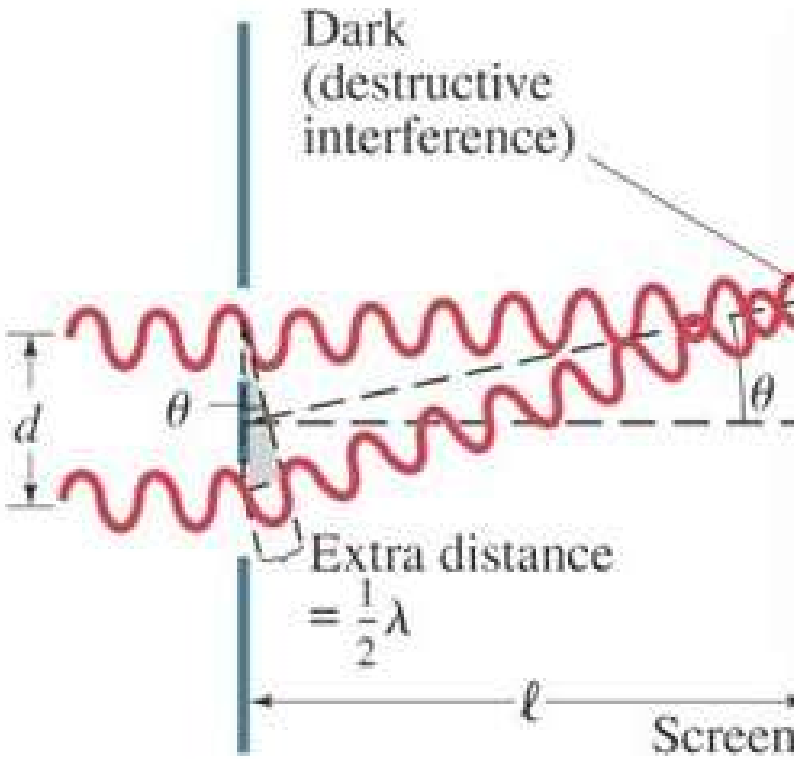
- Constructive interference also occurs when the path of the 2 rays differ by one wavelength (or any whole number of wavelengths).



(b)

7.4 INTERFERENCE

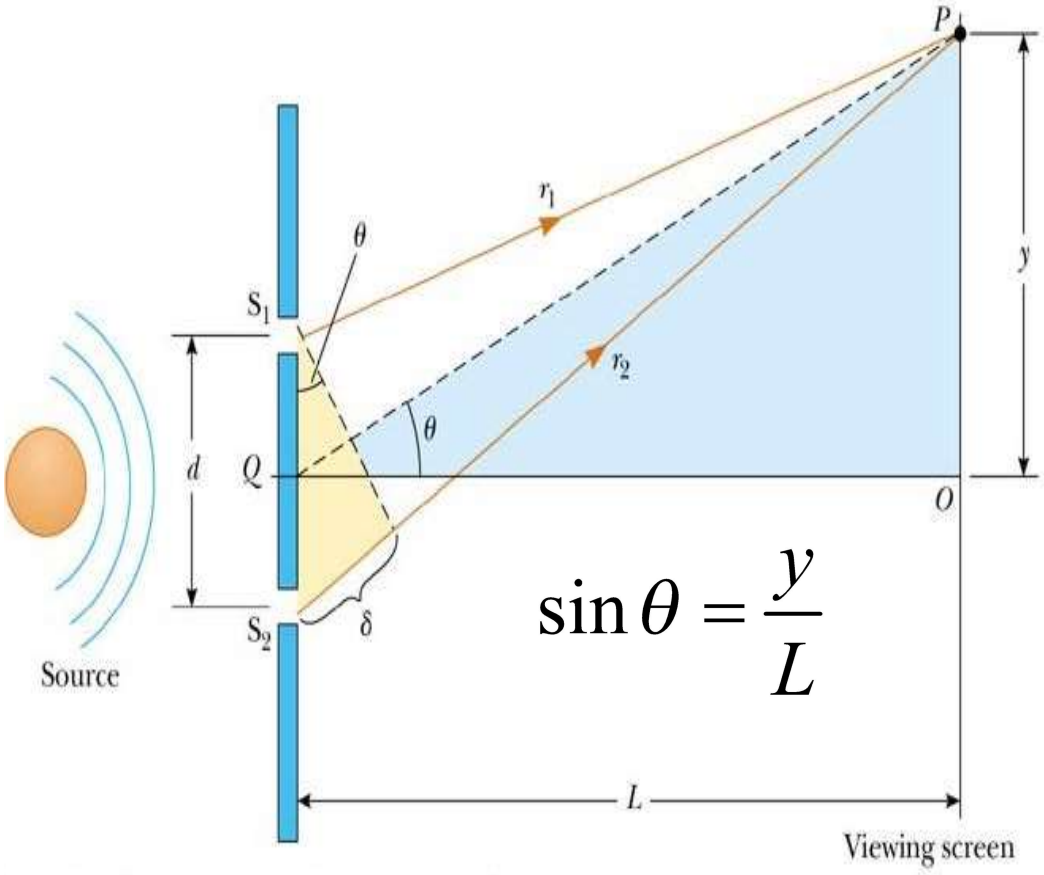
- Meanwhile, if one rays travels extra distance of one-half wavelength, the two waves are exactly out of phase when they reach the screen.
  - The crests of one wave arrive at the same time as the troughs of the other wave
  - Produce 0 amplitude
  - A destructive interference produced.



(c)

- Mathematic Representation of Young's 2 slits experiment

- The path difference, δ, is found from the tan shaded triangle.
- **$\delta = r_2 - r_1$**
  $= d \sin \theta$
  - This assumes the paths are parallel
  - Not exactly, but a very good approximation



7.4 INTERFERENCE

- For a bright fringe, produced by **constructive interference**, the **path difference** must be either **zero** or **some integral multiple of the wavelength**
- $\delta = d \sin \theta_{bright} = m \lambda = d(y/L)$

  Where,

  m is called the ***order number***

  m = 0, ±1, ±2, …

  - When m = 0, it is the zeroth order maximum
  - When m = ±1, it is called the first order maximum

7.4 INTERFERENCE

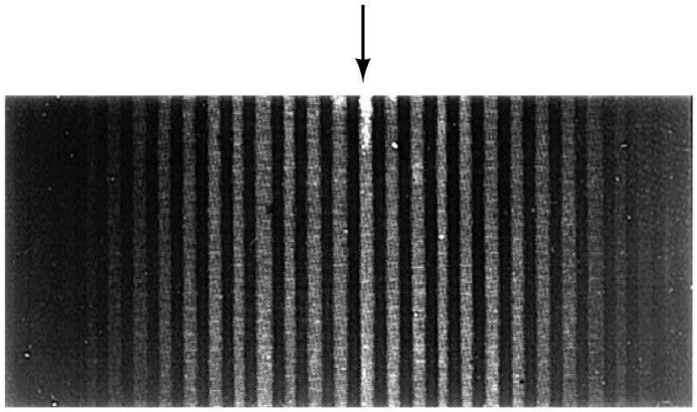
- For a dark fringe, produced by **destructive interference**, the **path difference** must be **some (integral+ ½) multiple of the wavelength**
- $\delta = d \sin \theta_{dark} = (m+1/2)\,\lambda = d(y/L)$

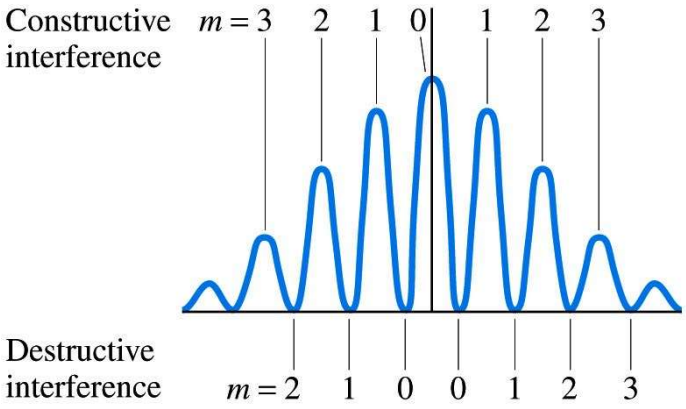
  Where,

  m is called the ***order number***

  m = 0, ±1, ±2, …

7.4 INTERFERENCE

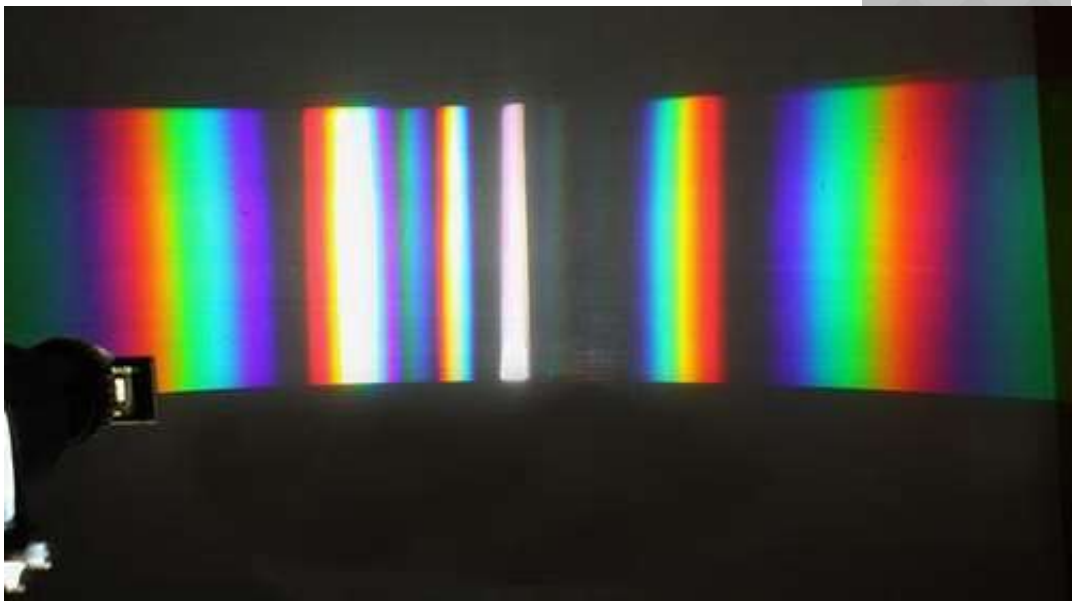




- Interference fringes produces by a double slit experiment and detected by photographic film placed on the viewing screen The arrows marks the central fringe.
- Intensity of light in the interference pattern. Also shown are values of *m* for constructive and destructive interference.

The Diffraction Grating

- The diffracting grating consists of a large number of line, equidistant, closely spaced parallel lines of equal width , ruled on glass or polished metal by a diamond point.
  - A typical grating contains several thousand lines per centimeter
- The intensity of the pattern on the screen is the result of the combined effects of interference and diffraction

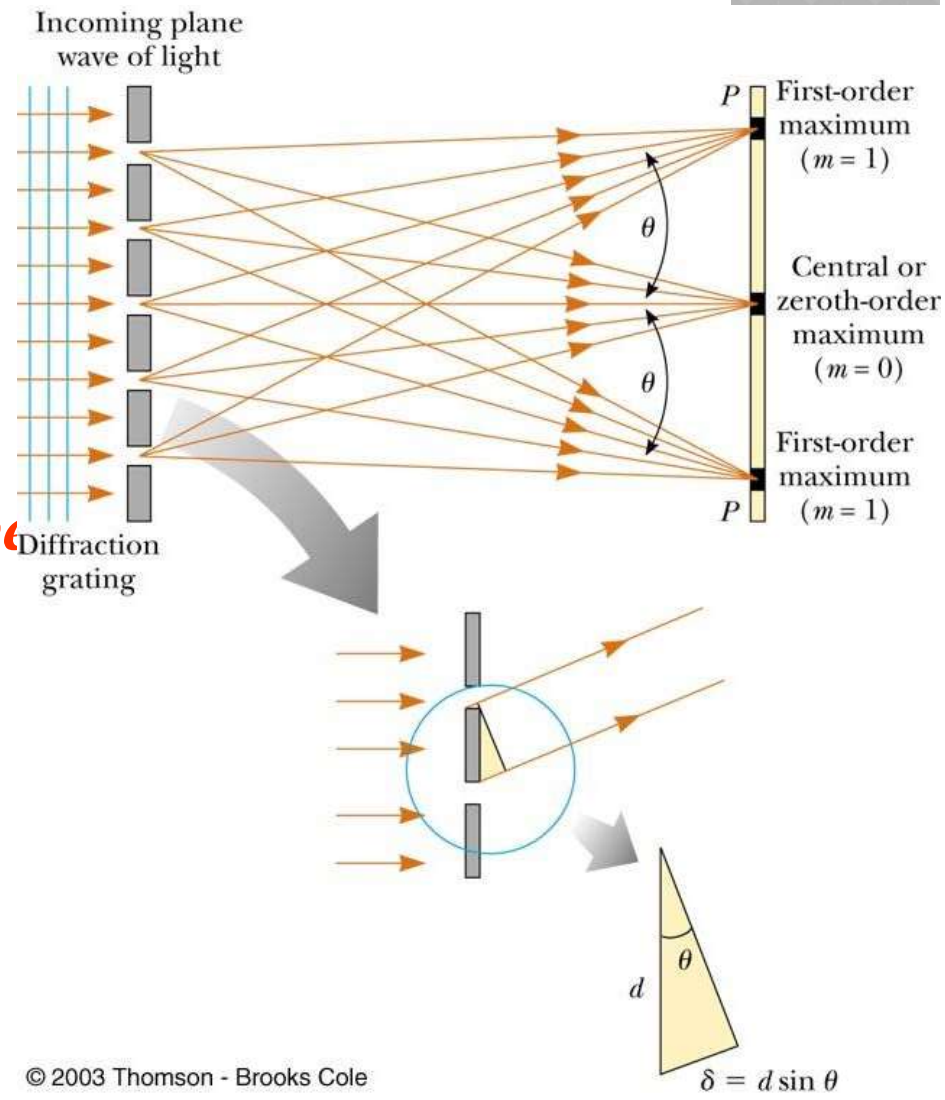


7.5 DIFFRACTION OF LIGHT

- The pattern observed on the screen is the result of the combined effects of interference and diffraction
- Each slit produces diffraction and the diffracted beams interfere with each other to produce the final pattern.
- Each slit acts as a source of waves where all waves start at the slit in phase.

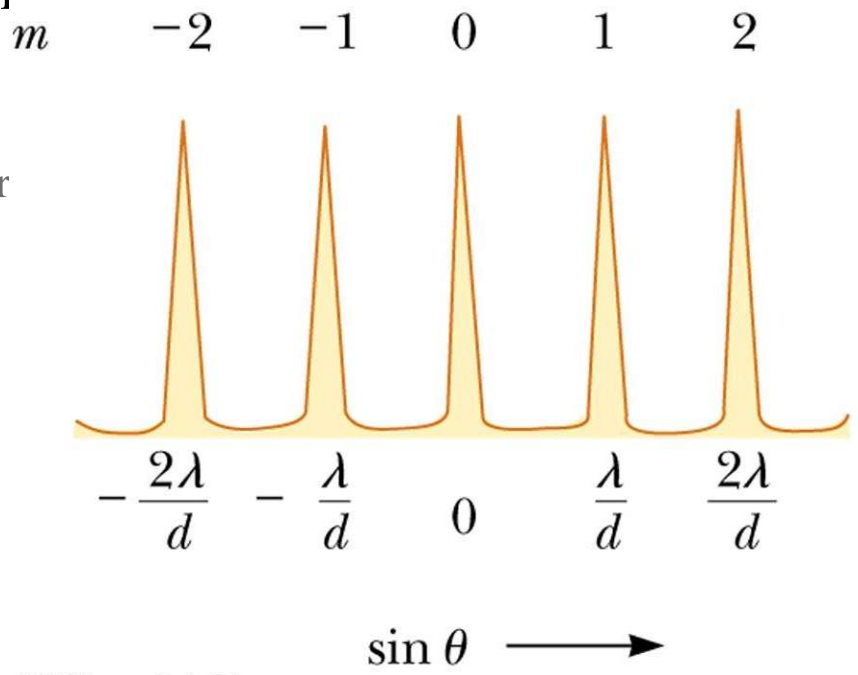
7.5 DIFFRACTION OF LIGHT

- Path difference between waves from any two adjacent slits is d sin θ
- The condition for ***maxima*** is
  - $d \sin \theta_{bright} = m \lambda$
    - $m = 0, \pm 1, \pm 2, \ldots$
    - d=1/N(cm)
    - N : number of lines / cm
- The integer ***m*** is the ***order numbe*** of the diffraction pattern
- If the incident radiation contains several wavelengths, each wavelength deviates through a specific angle

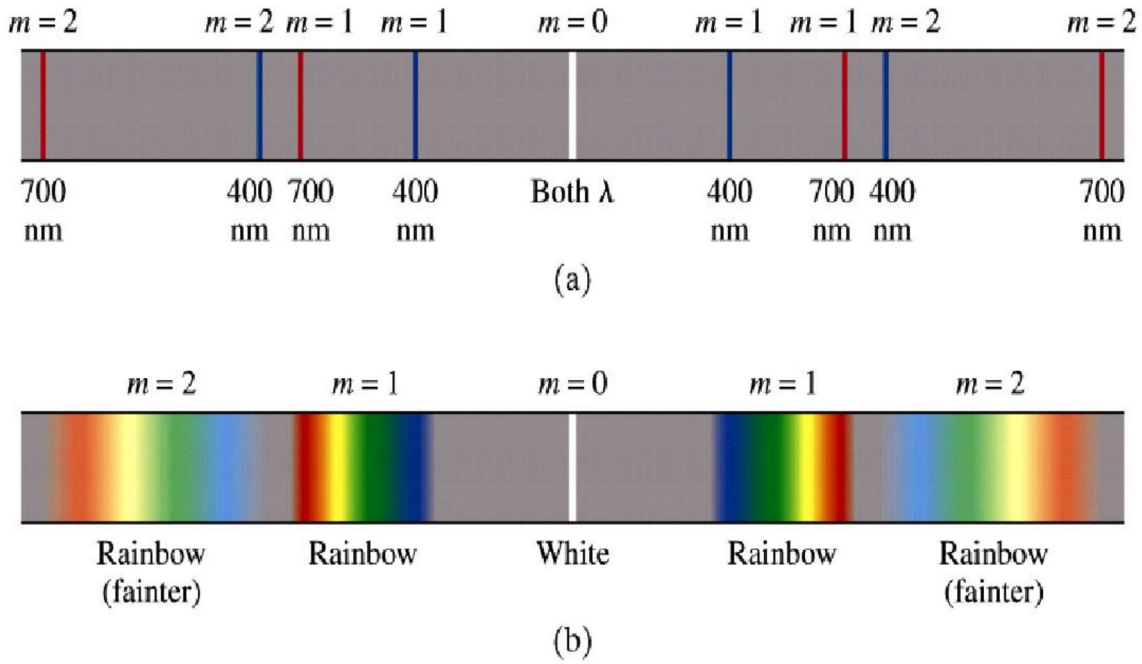


7.5 DIFFRACTION OF LIGHT

- All the wavelengths are focused at m = 0
  - This is called the zero-th order maximum
- The first order maximum corresponds to m = 1
- Note the sharpness of the principle maxim and the broad range of the dark are
  - This is in contrast to the broad, bright fringes characteristic of the two-slit interference patter



7.5 DIFFRACTION OF LIGHT



- two wavelengths, 400 nm and 700 nm
- white light strikes the grating , the central max will be sharp white. But for all other orders there will be a distinct spectrum colors spread over a certain angular width because the diffraction grating spread out light into its component wavelength.


Thank You...
You made my day !