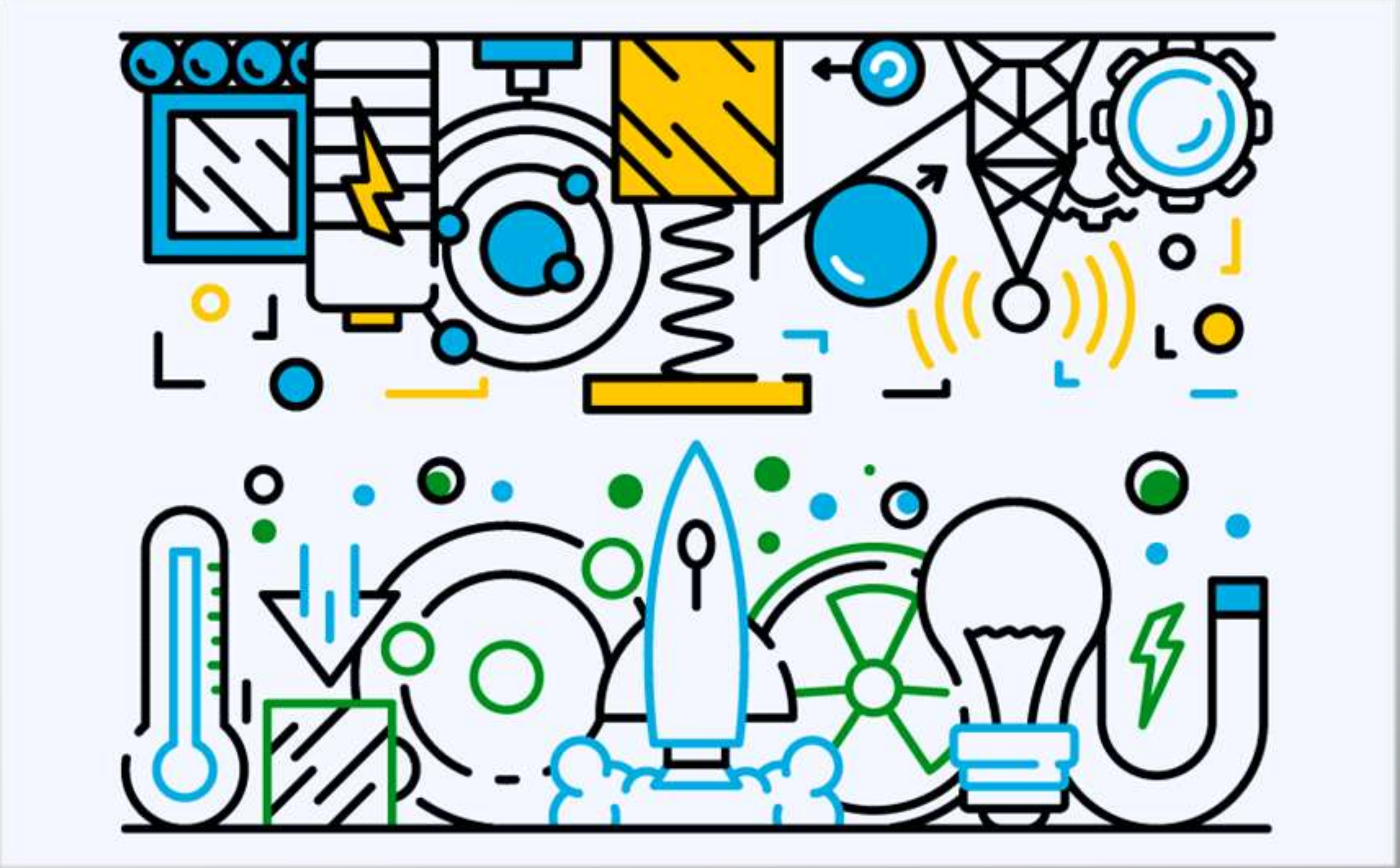
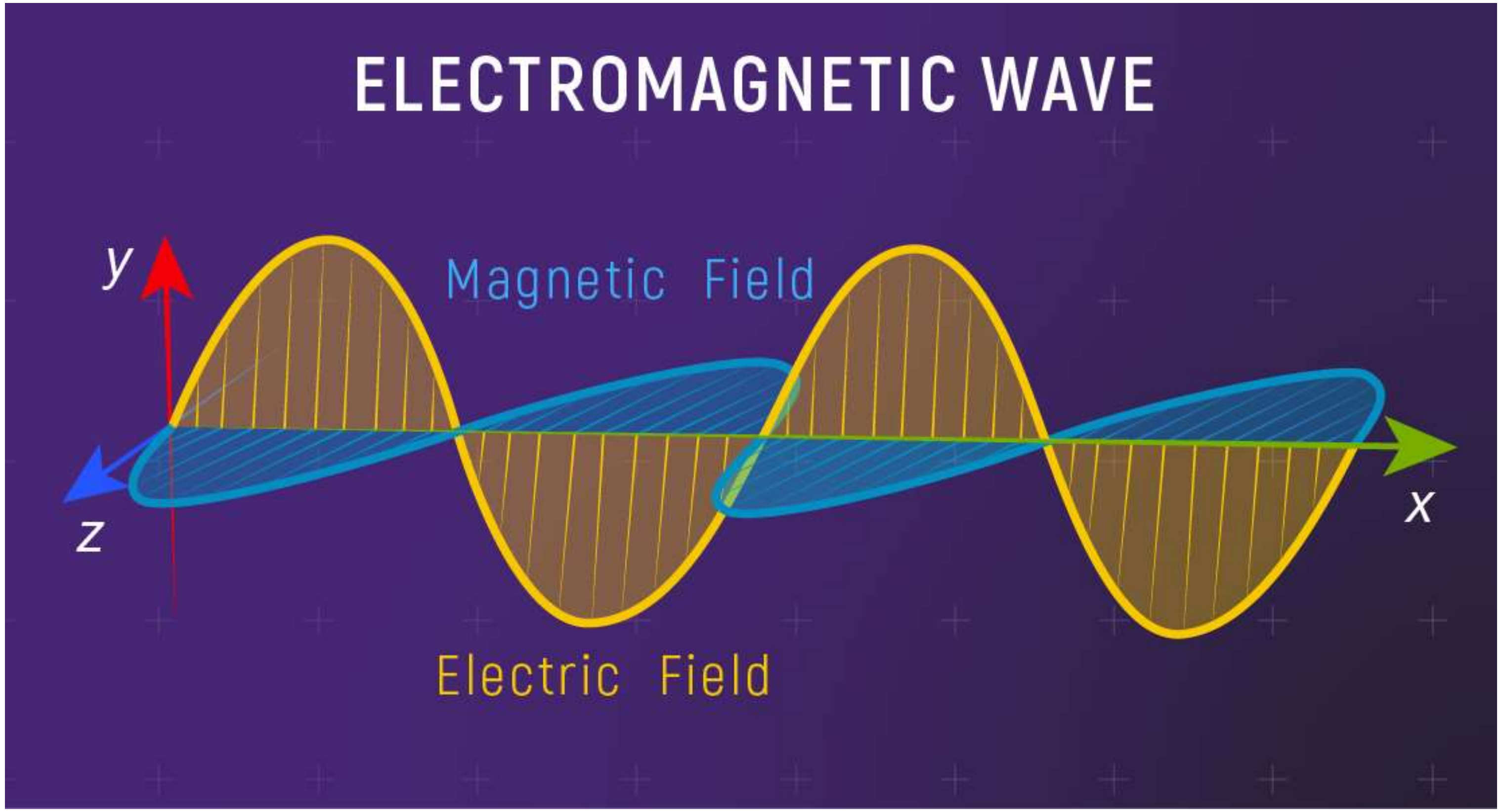
Engineering Physics (FIC 102)

UNIT-II



CONTENT

LECTURE-01



Electromagnetic Wave

CONCEPT QUESTION

In a long line of people waiting to buy tickets, the first person leaves and a pulse of motion occurs as people step forward to fill the gap.

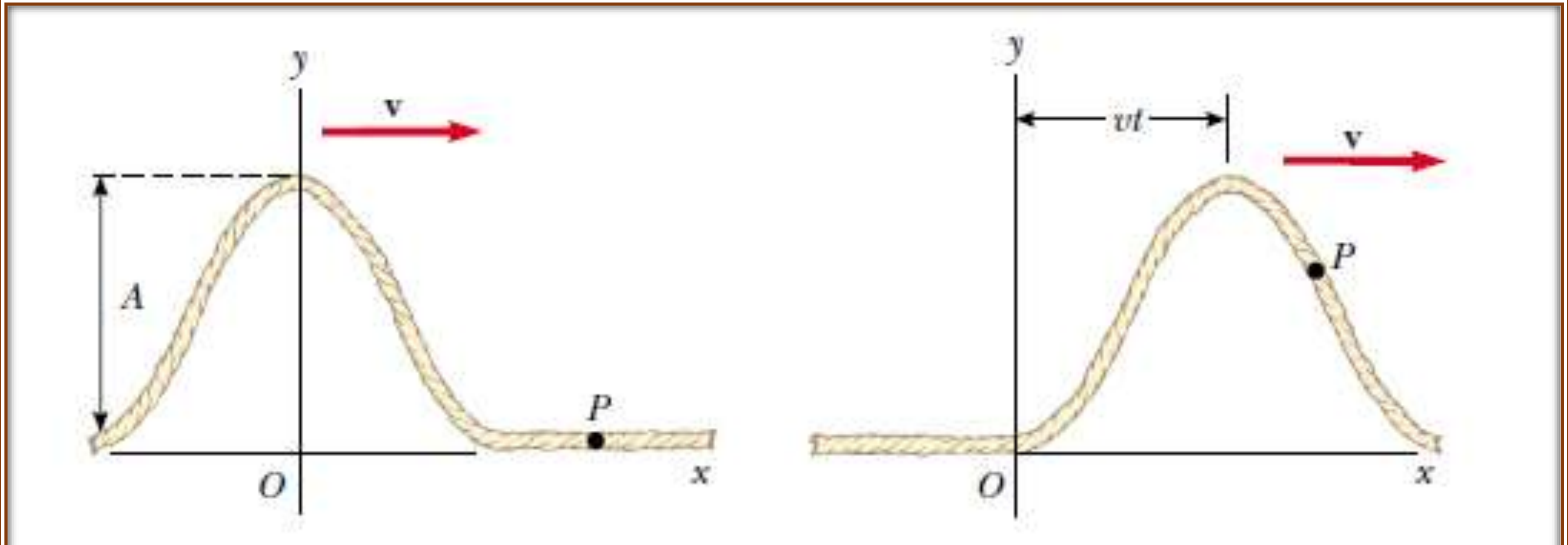
As each person steps forward, the gap moves through the line.

Is the propagation of this gap

(a) transverse

(b) longitudinal?

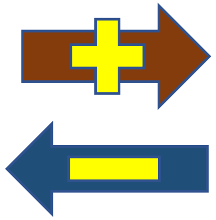
BASICS OF WAVE PROPAGATION



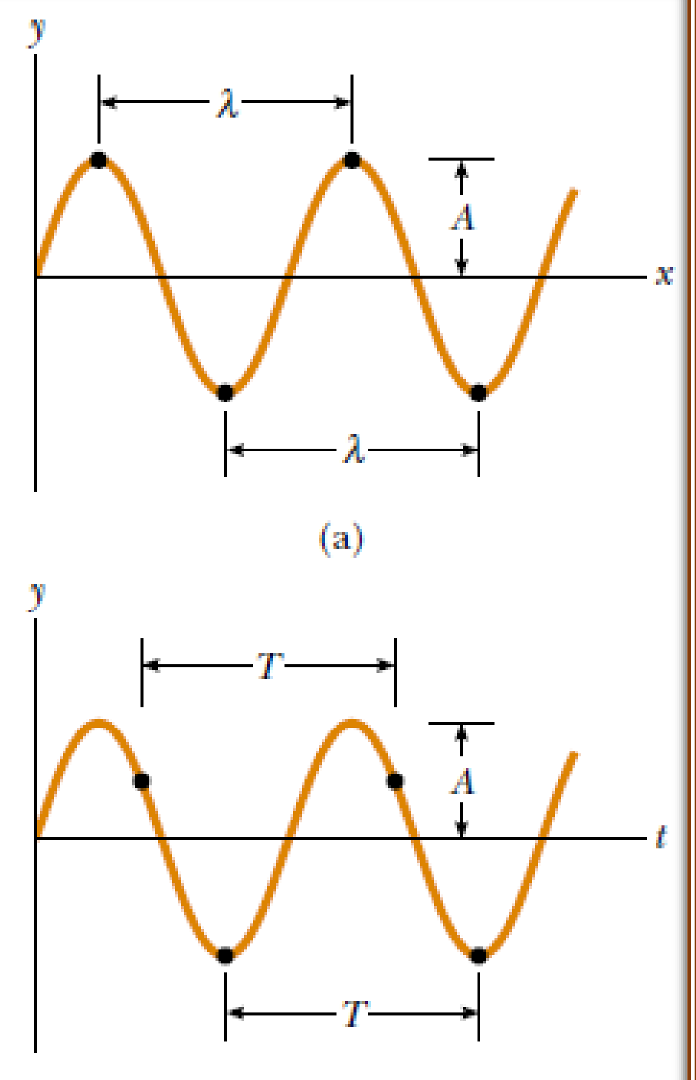
(a) Pulse at $t = 0$ (b) Pulse at time t

PULSE WAVE

$$y(x,t) = f(x \pm vt)$$



BASICS OF WAVE PROPAGATION



(a)

(b)

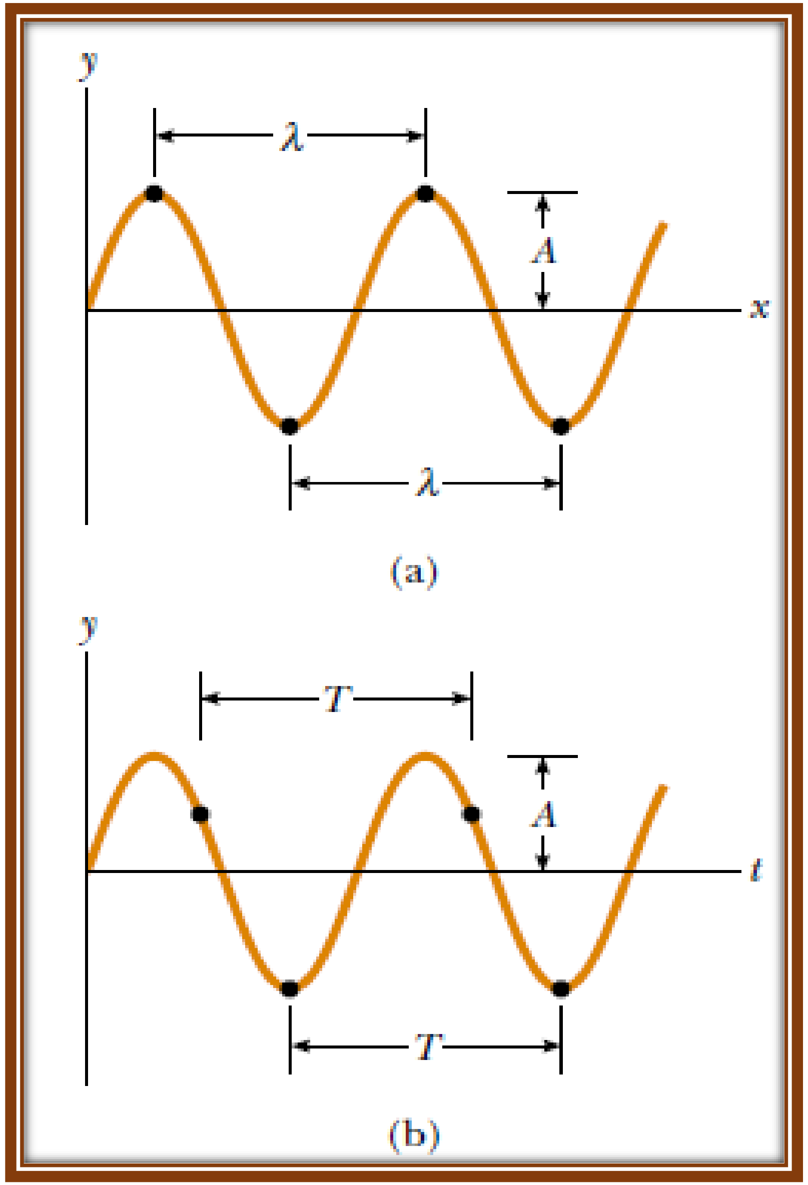
$$y_1 = A\sin(kx \pm \omega t) \;= A\sin\left(\frac{2\pi}{\lambda}[x \pm vt]\right)$$

$$y_1 = A\sin\left(2\pi\left[\frac{x}{\lambda} \pm \frac{t}{T}\right]\right)$$

$$\boxed{v = \frac{\omega}{k} \equiv \lambda f} \quad \boxed{k = \frac{2\pi}{\lambda}} \quad \boxed{\omega = \frac{2\pi}{T}} \quad \boxed{f = \frac{1}{T}}$$

TRAVELING WAVE

BASICS OF WAVE PROPAGATION



$$y_1 = A\sin\left(2\pi\left[\frac{x}{\lambda} \pm \frac{t}{T}\right] + \varphi\right)$$

$\lambda \Rightarrow Wavelength$ $\quad T \Rightarrow Time\ period$

$k \Rightarrow Angular\ Wave\ number$

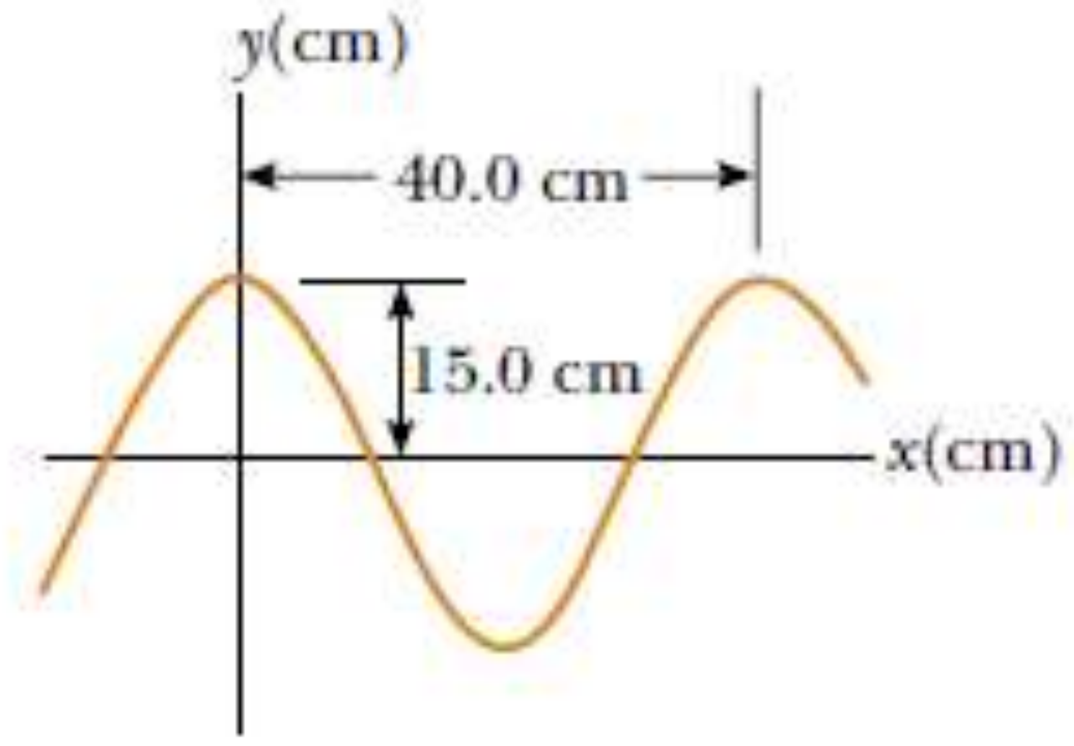
$\omega \Rightarrow Angular\ frequency$

$f \Rightarrow Frequency$ $\quad \varphi \Rightarrow Phase\ Constant$

TRAVELING WAVE

SOLVED EXAMPLE

- A sinusoidal wave traveling in the positive x direction has an amplitude of 15.0 cm, a wavelength of 40.0 cm, and a frequency of 8.00 Hz.
- The vertical position of an element of the medium at t = 0 and x = 0 is also 15.0 cm, as shown in the Figure.
- Find the wave number k, period T, angular frequency f, speed v and phase constant φ of the wave.



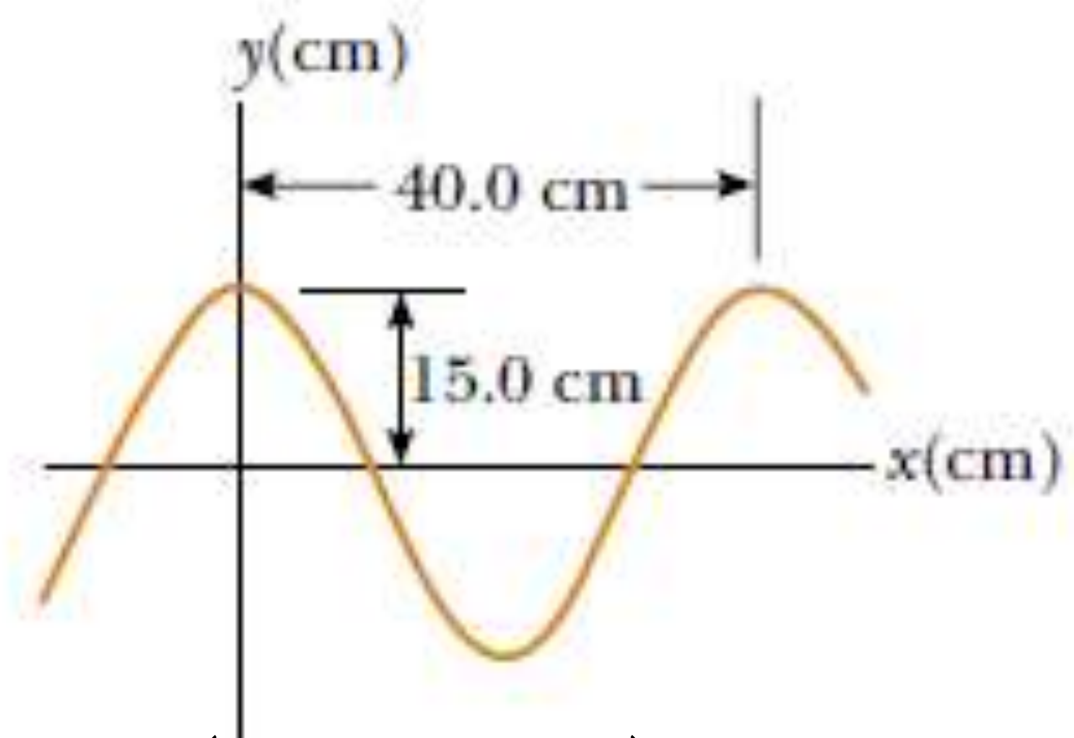
SOLVED EXAMPLE

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.4} = 5\pi \, rad/m$$

$$T = \frac{1}{f} = \frac{1}{8} = 0.125s$$

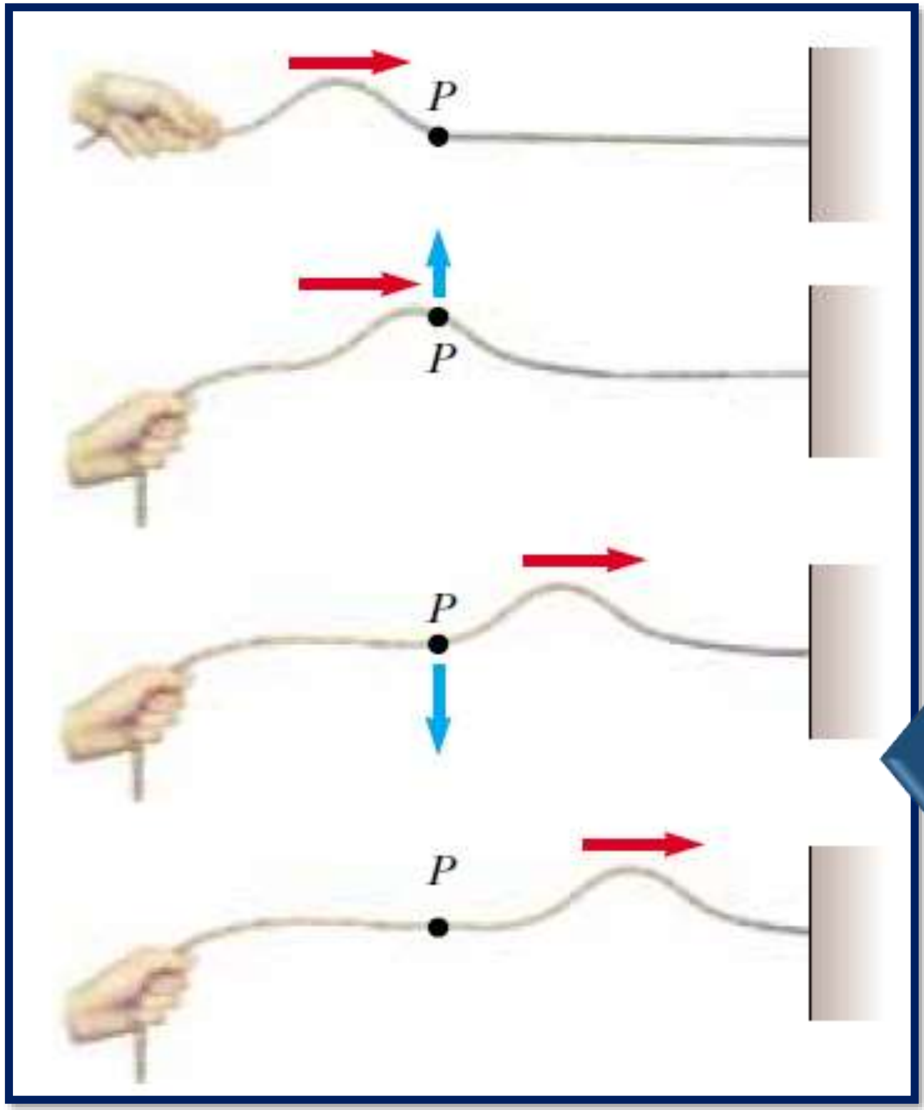
$$\omega = \frac{2\pi}{T} = 2\pi f = 16\pi \, rad/s$$

$$v = \lambda f = (0.4m)(8.0s^{-1}) = 3.2 \, m/s$$



$$\varphi = \sin^{-1}\left(\frac{y\{x=0, t=0\}}{A}\right) = \sin^{-1}(1) = \frac{\pi}{2}$$

TRANSVERSE WAVE

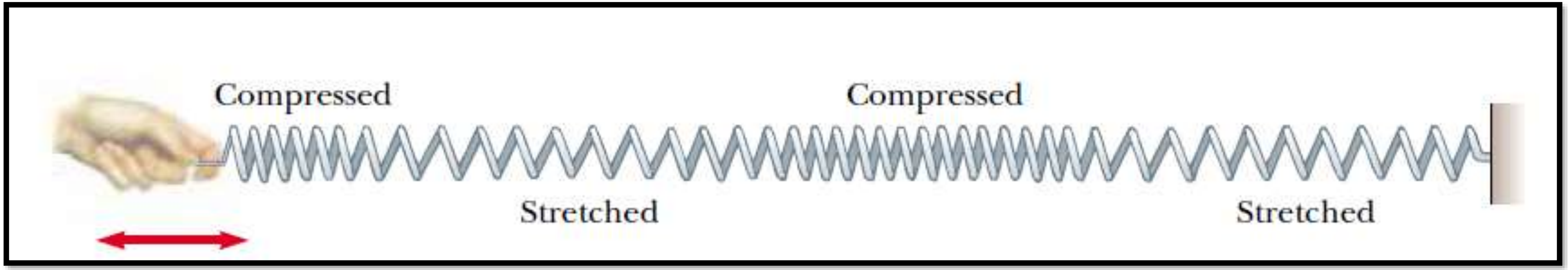


A traveling wave or pulse that causes the elements of the disturbed medium to move perpendicular to the direction of propagation is called a ***transverse wave***.

A transverse pulse traveling on a stretched rope. The direction of motion of any element P of the rope (blue arrows) is perpendicular to the direction of propagation (red arrows).

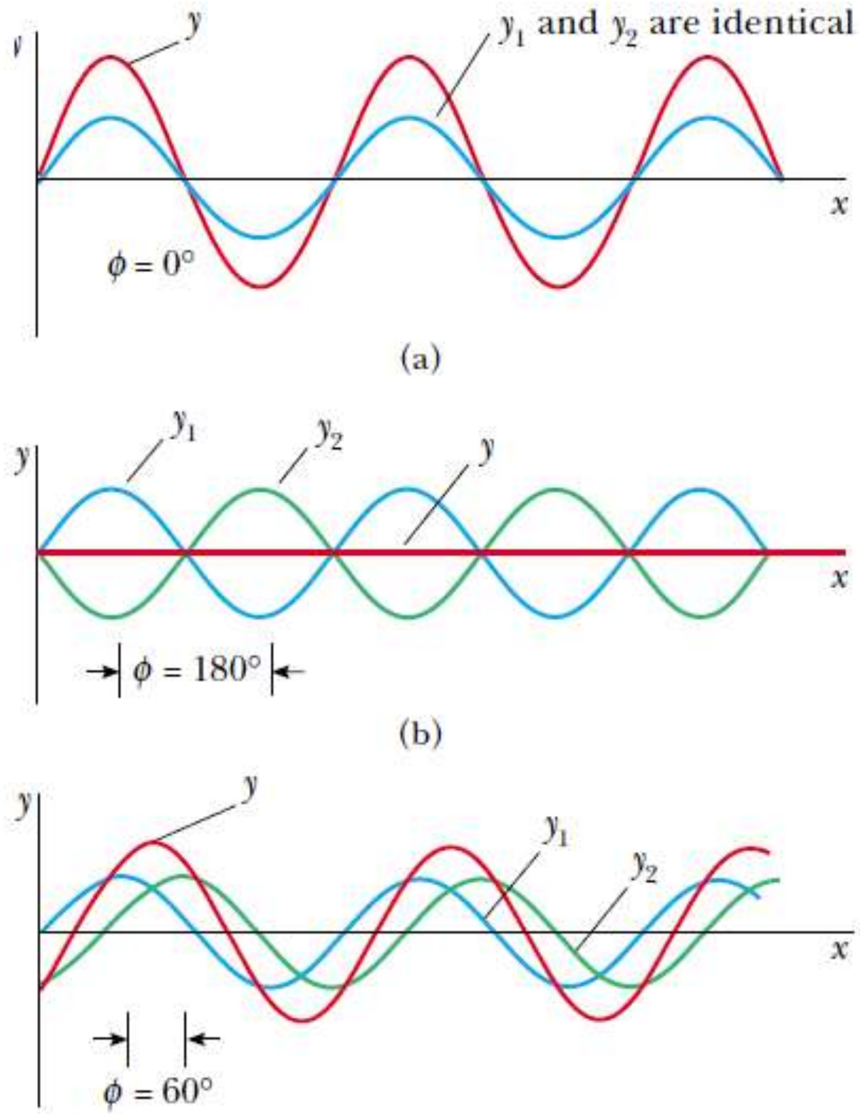
LONGITUDINAL WAVE

A traveling wave or pulse that causes the elements of the medium to move parallel to the direction of propagation is called a ***longitudinal wave***.



A longitudinal pulse along a stretched spring. The displacement of the coils is parallel to the direction of the propagation.

Superposition of Sinusoidal Waves



Assume wave equations:

$$y_1 = A\sin(kx - \omega t) \ and \ \ y_2 = A\sin(kx - \omega t + \varphi)$$

$$So\ y = y_1 + y_2 = 2Acos\left(\frac{\varphi}{2}\right)\sin\left(kx - \omega t + \frac{\varphi}{2}\right)$$

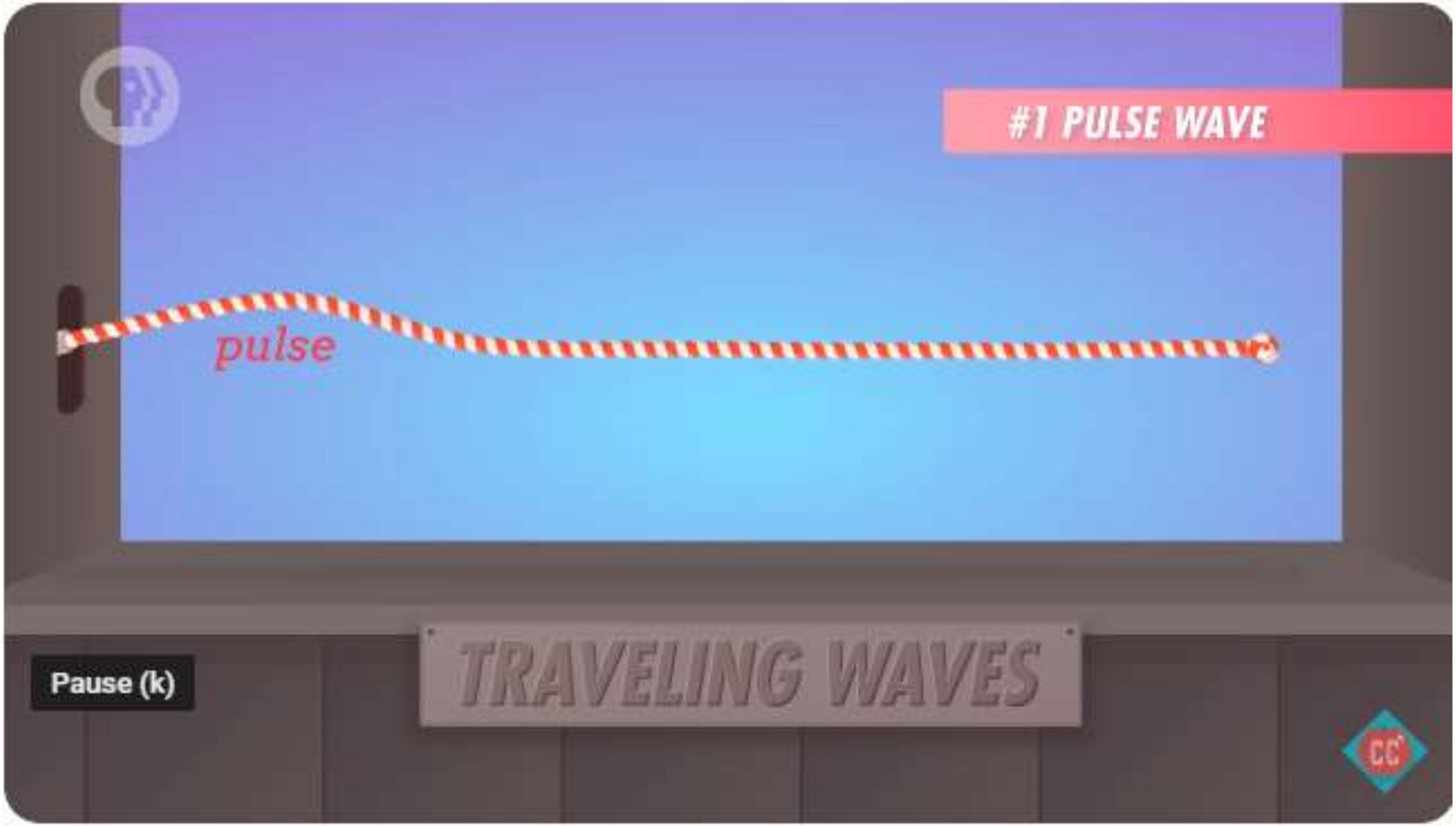
$$When\ \varphi = 0^o\ everything\ simply\ add\ up$$

$$When\ \varphi = 180^o\ resultant\ wave\ just\ vanishes$$

$$When\ \varphi\ has\ intermediate\ values\ resultant\ wave$$
$$take\ differnent\ forms\ depending\ on\ the\ value\ of\ \varphi$$

$$\boxed{\sin a + \sin b = 2\cos\left(\frac{a-b}{2}\right)\sin\left(\frac{a+b}{2}\right)}$$

INTERACTIVE VIDEO



EM WAVE PROPERTIES

Electromagnetic Waves is a special type of transverse wave.

EM Wave propagates combining an electrical transverse wave and a magnetic transverse wave.

Unlike sound wave or water wave or waves on a string, EM Waves can propagate through empty space throughout the Universe – NO MEDIUM!

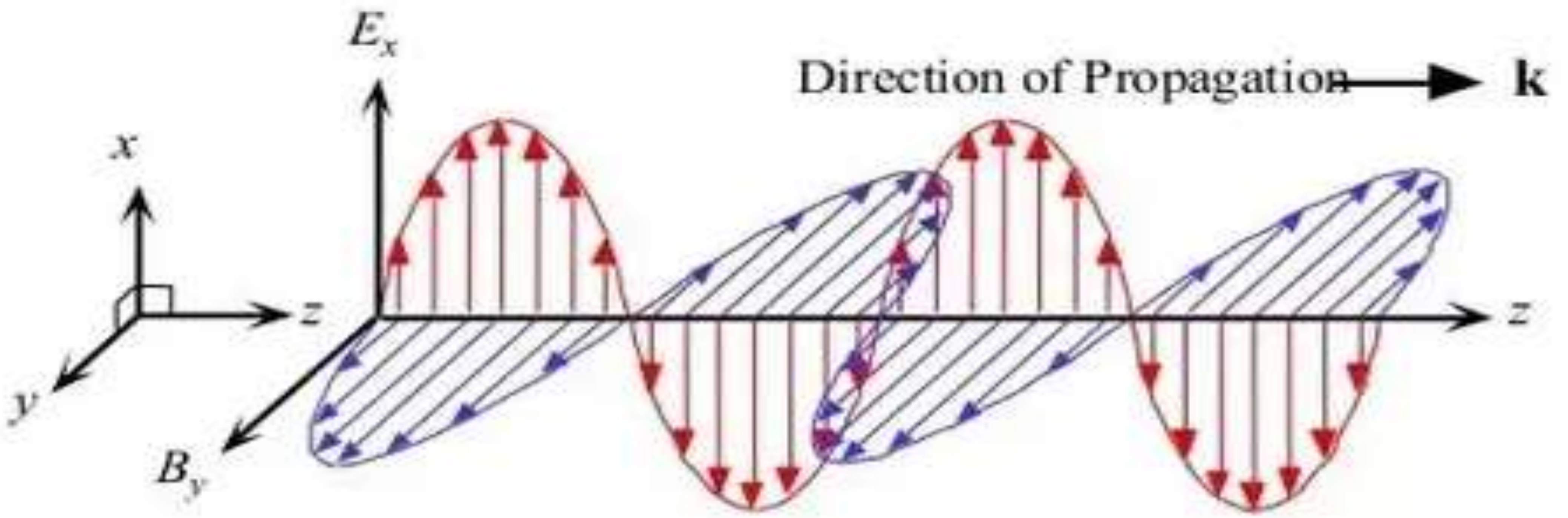
Both the waveforms take usual sinusoidal form.

Visible light is a part of electromagnetic waveform.

Velocity of EM Wave (and Light) in free space is $3x\ 10^8$ m/sec.

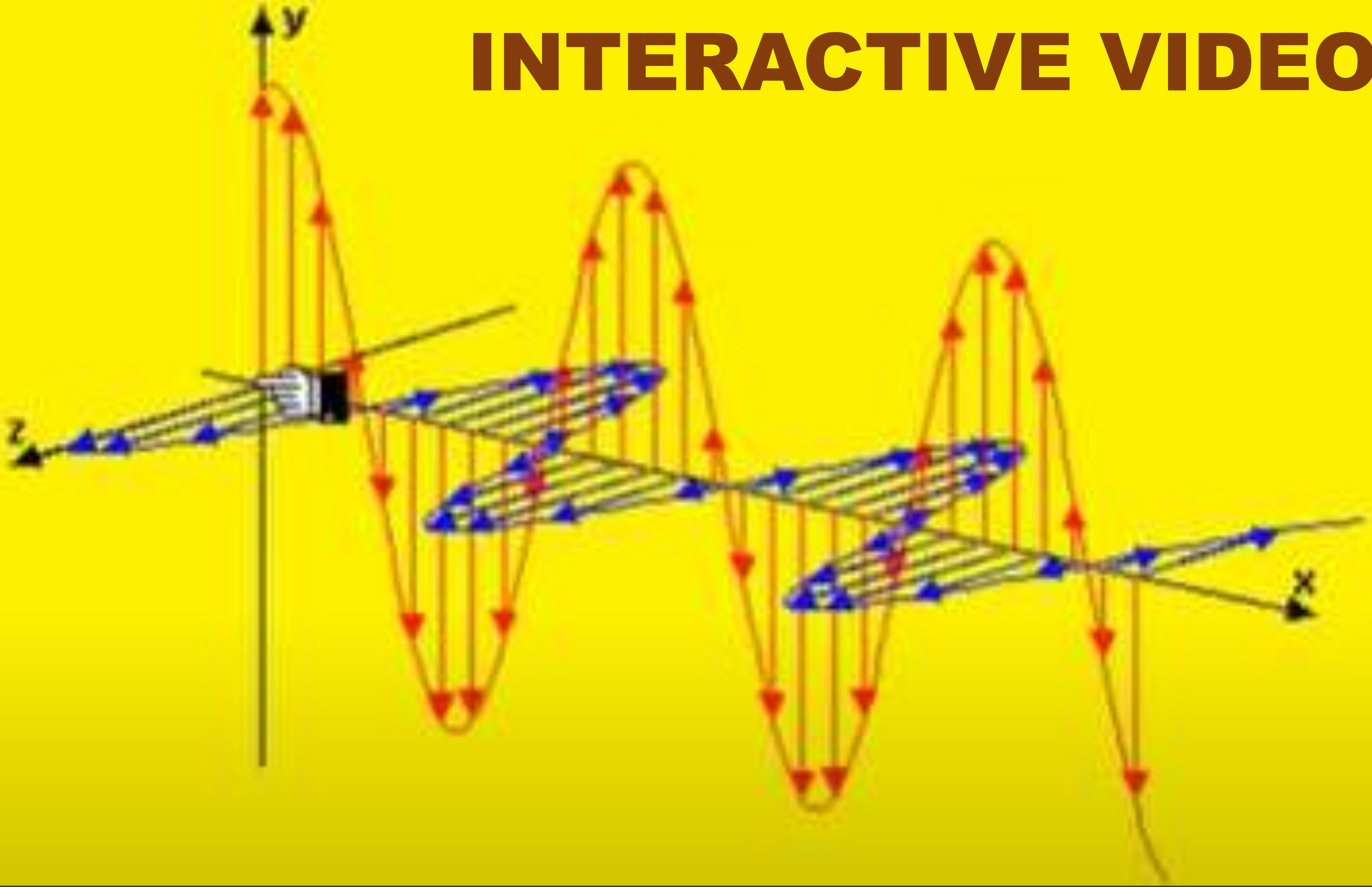
According to the special theory of relativity **nothing** in this universe can move faster than this velocity!

EM WAVE PROPAGATION

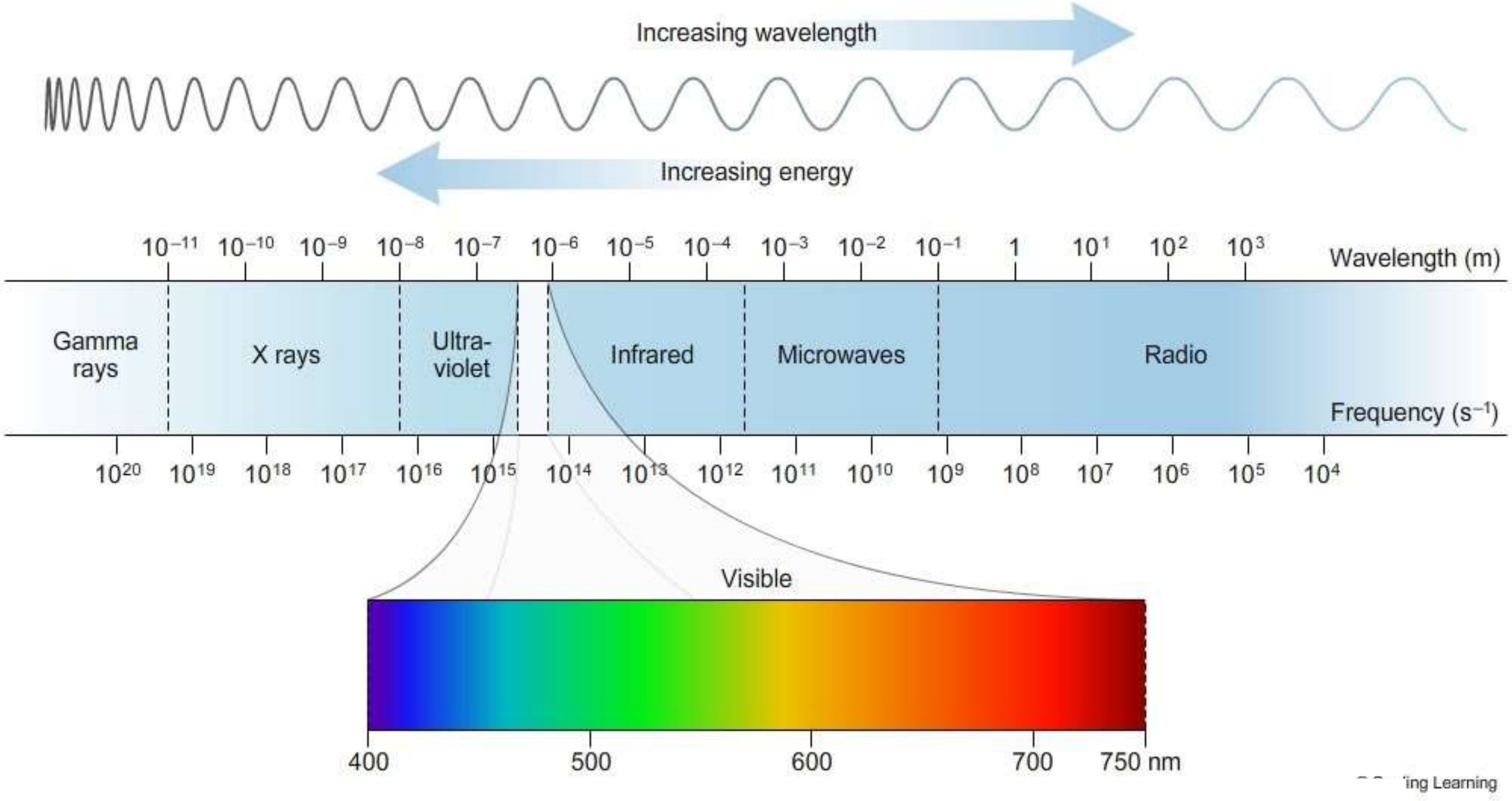


An electromagnetic wave is a travelling wave which has time varying electric and magnetic fields which are perpendicular to each other and the direction of propagation,

INTERACTIVE VIDEO



EM WAVE SPECTRA



$$v = \lambda f = c, f \text{ is denoted as } \nu \text{ generally}$$

VERY LARGE & VERY SMALL!

10^3	KILO
10^6	MEGA
10^9	GIGA
10^{12}	TERRA
10^{15}	PETA
10^{18}	EXA

10^{-3}	MILI
10^{-6}	MICRO
10^{-9}	NANO
10^{-12}	PICO
10^{-15}	FEMTO
10^{-18}	ATTO

POLL QUESTIONS

Which of the following relationship is only incorrect

$A.\ 10^{-2}mm = 10\mu m$

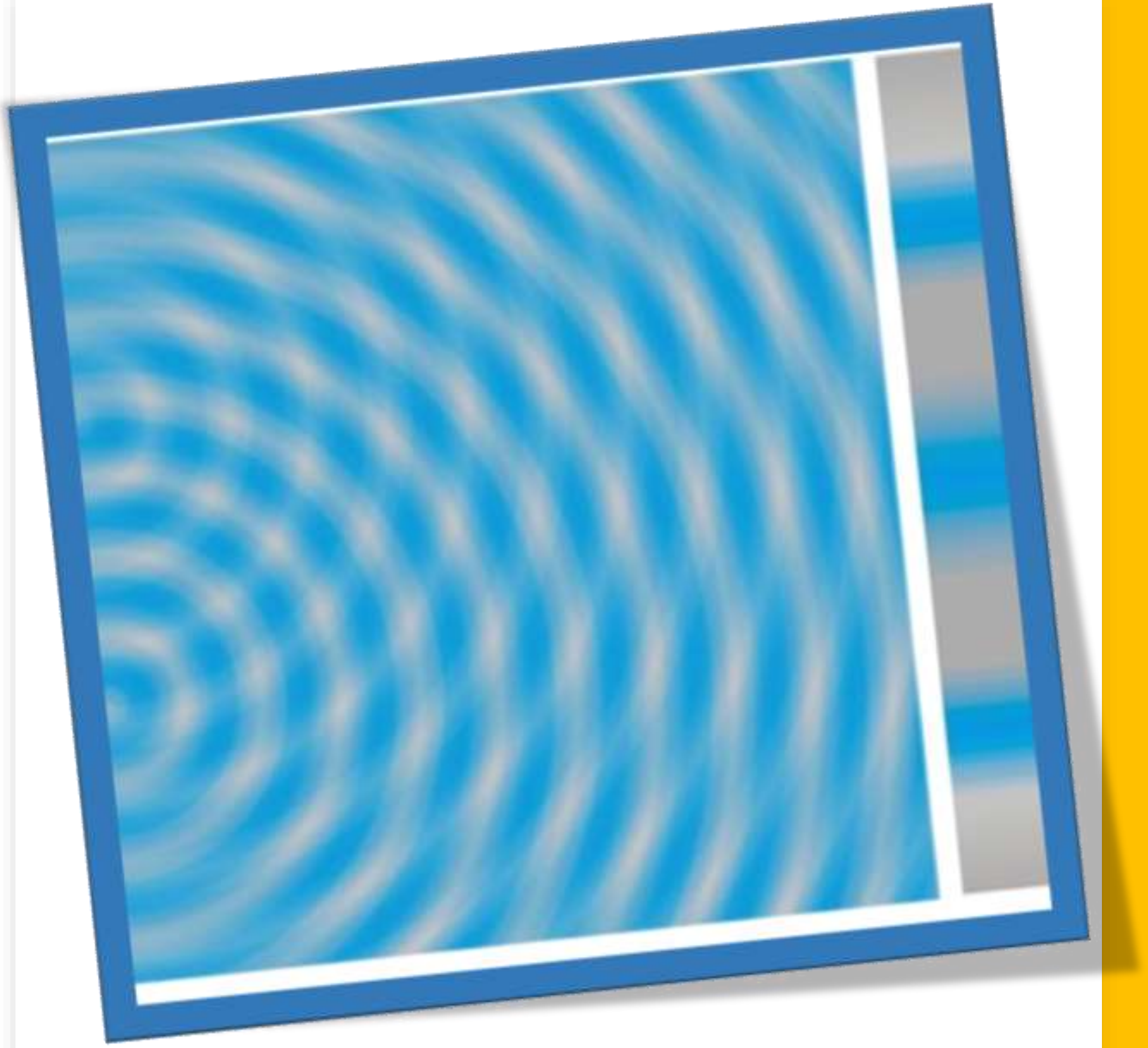
$B.\ 10^{10}Hz = 10MHz$

$C.\ 10^{13}Hz = 10{,}000GHz$

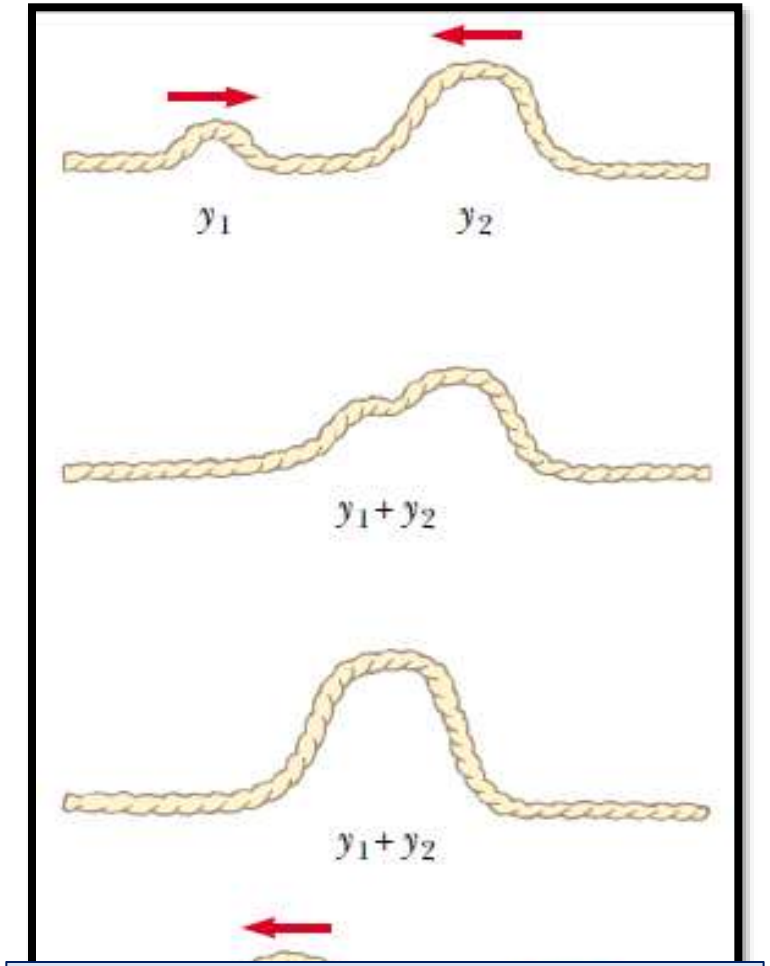
$D.\ 10^{20}Hz = 100EHz$

LECTURE-02

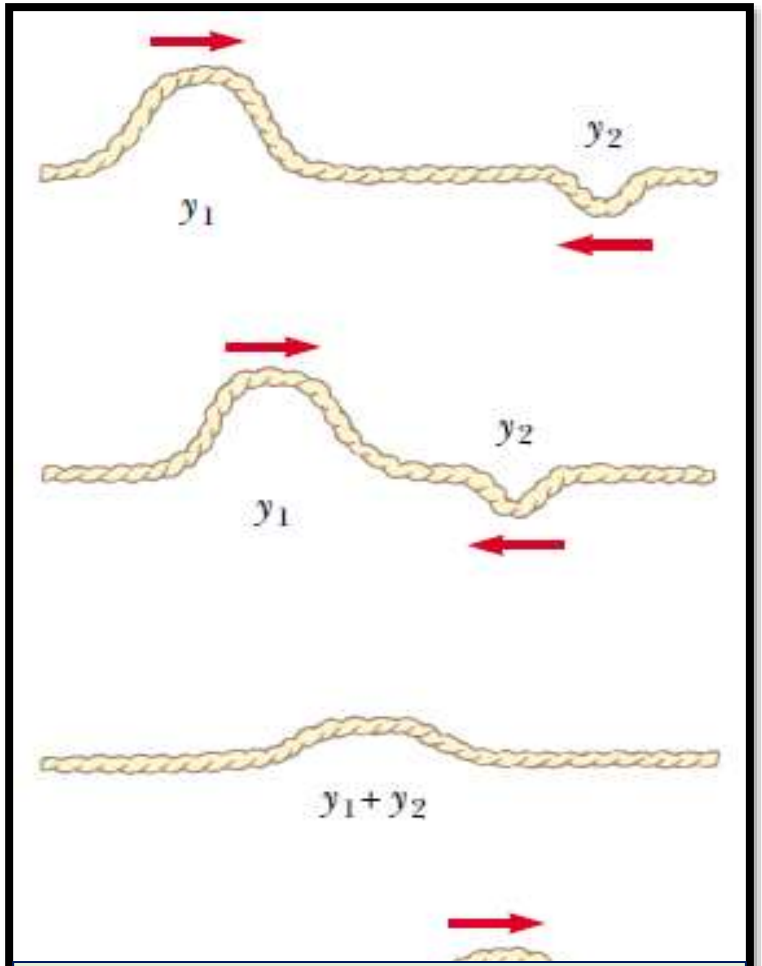
Wave Property of Light
: Interference



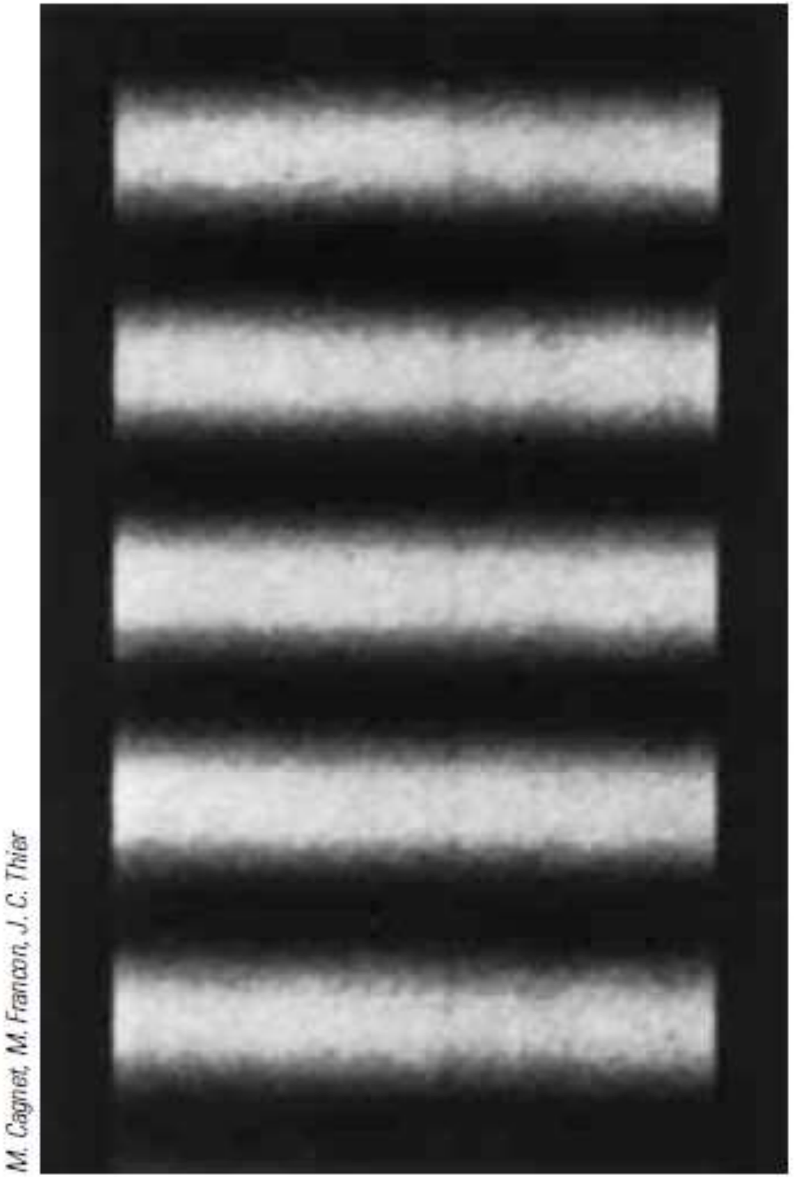
Interference of Waves



Constructive Interference of Mechanical Waves



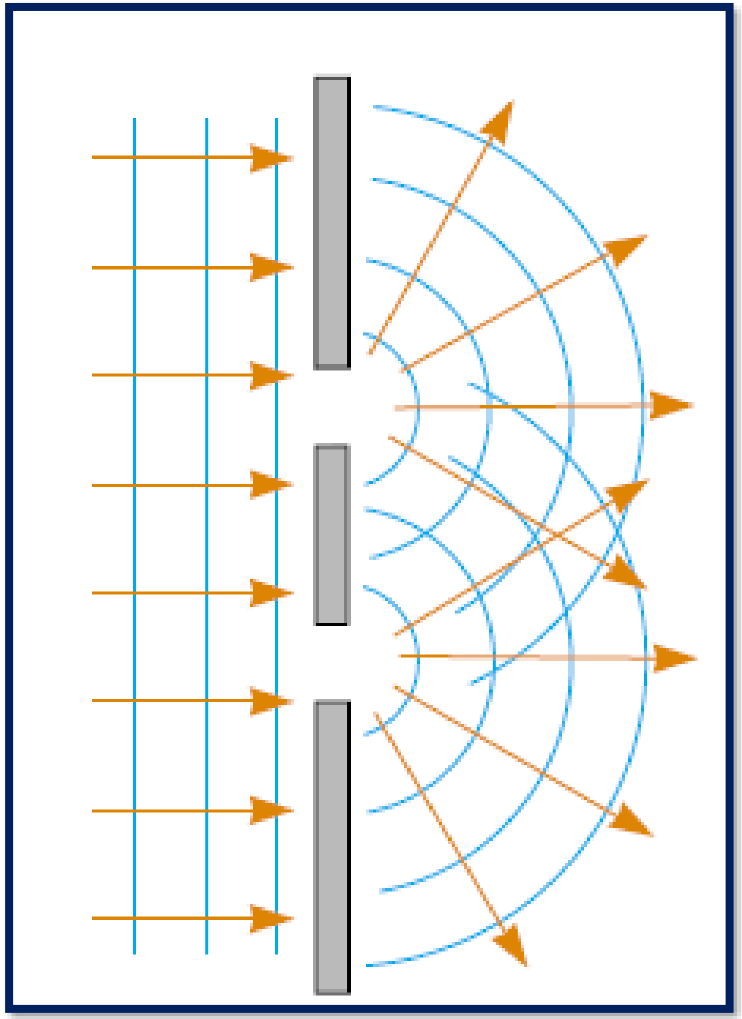
Destructive interference of Mechanical Waves.



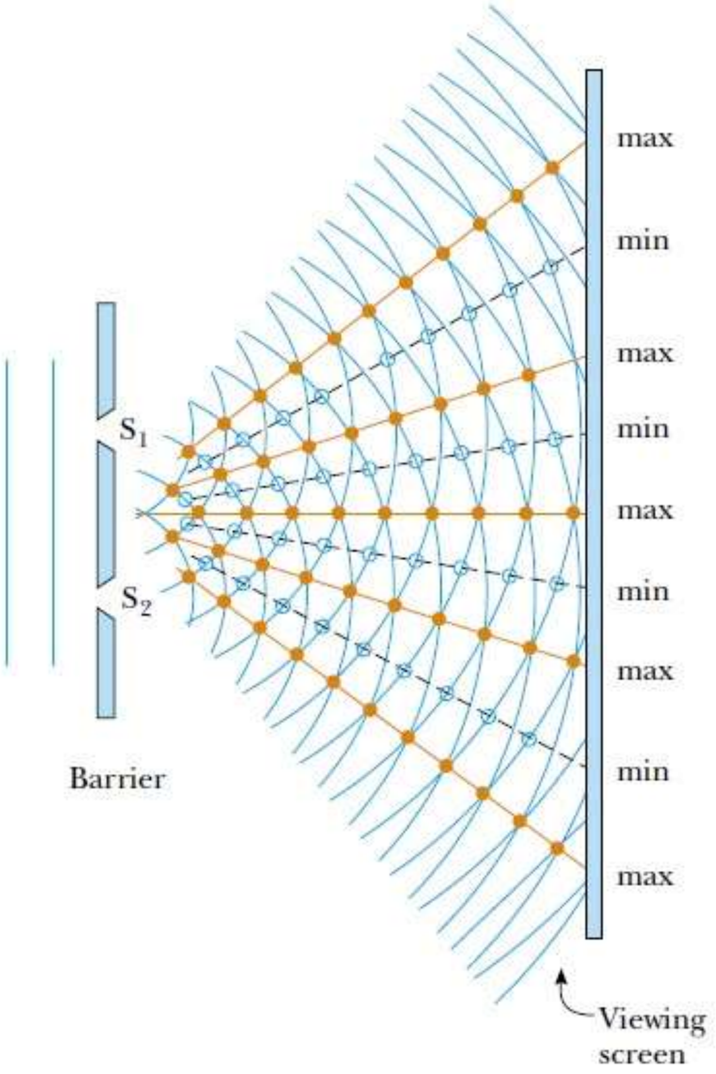
CONDITIONS OF INTERFERENCE

- If two lightbulbs are placed side by side, no interference can be observed.
- In order to observe interference in light waves, the following conditions must be met:

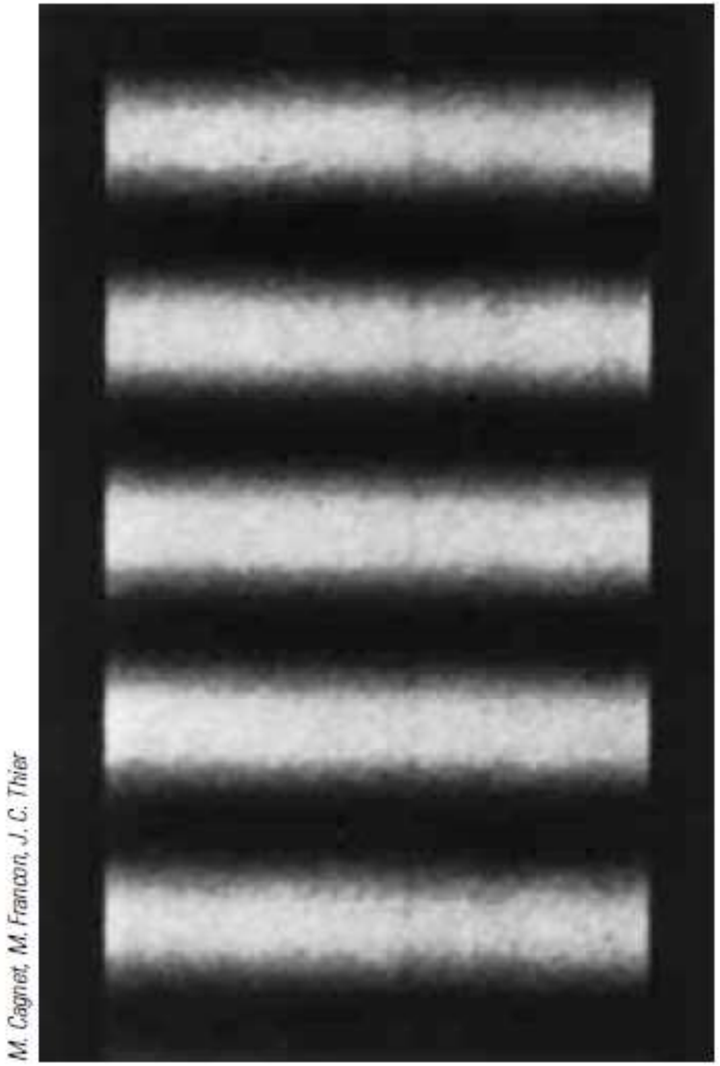
1) *The sources must be* ***coherent****—that is, they must maintain a constant phase with respect to each other.*
2) *The sources should be* ***monochromatic****—that is, of a single wavelength.*



Young double slit experiment

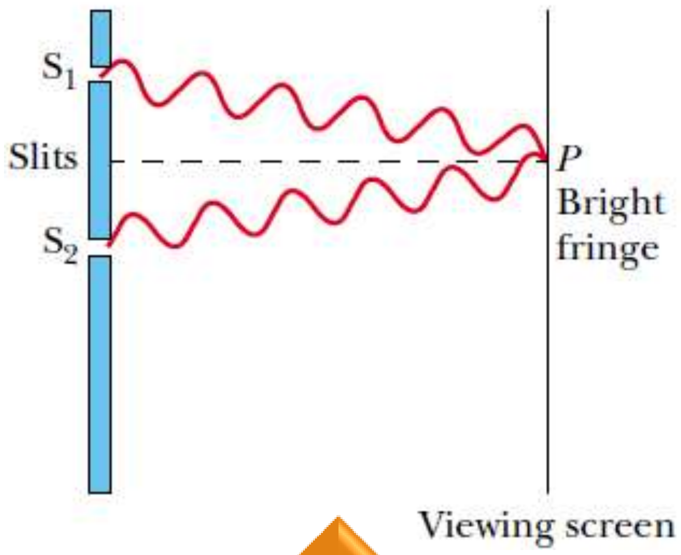


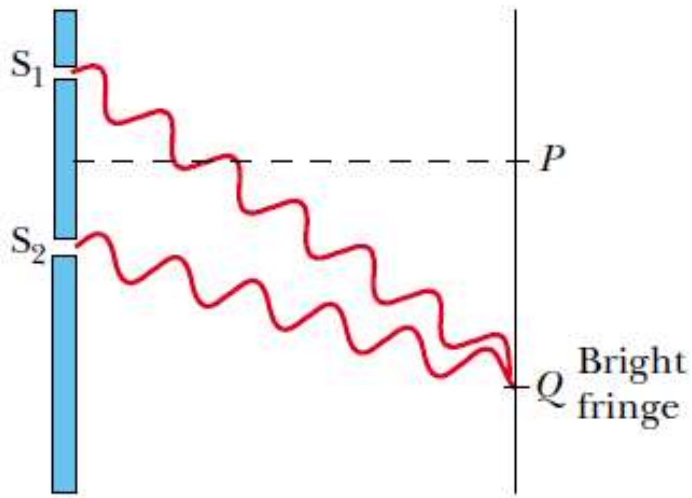
Schematic diagram of Young's double-slit experiment. Slits S1& S2 act as Coherent Sources

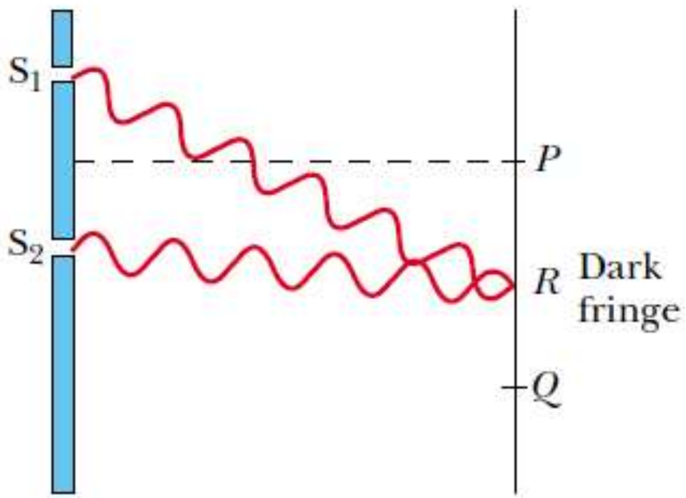


An enlargement of the center of a fringe pattern formed on the viewing screen.

Understanding the interference pattern







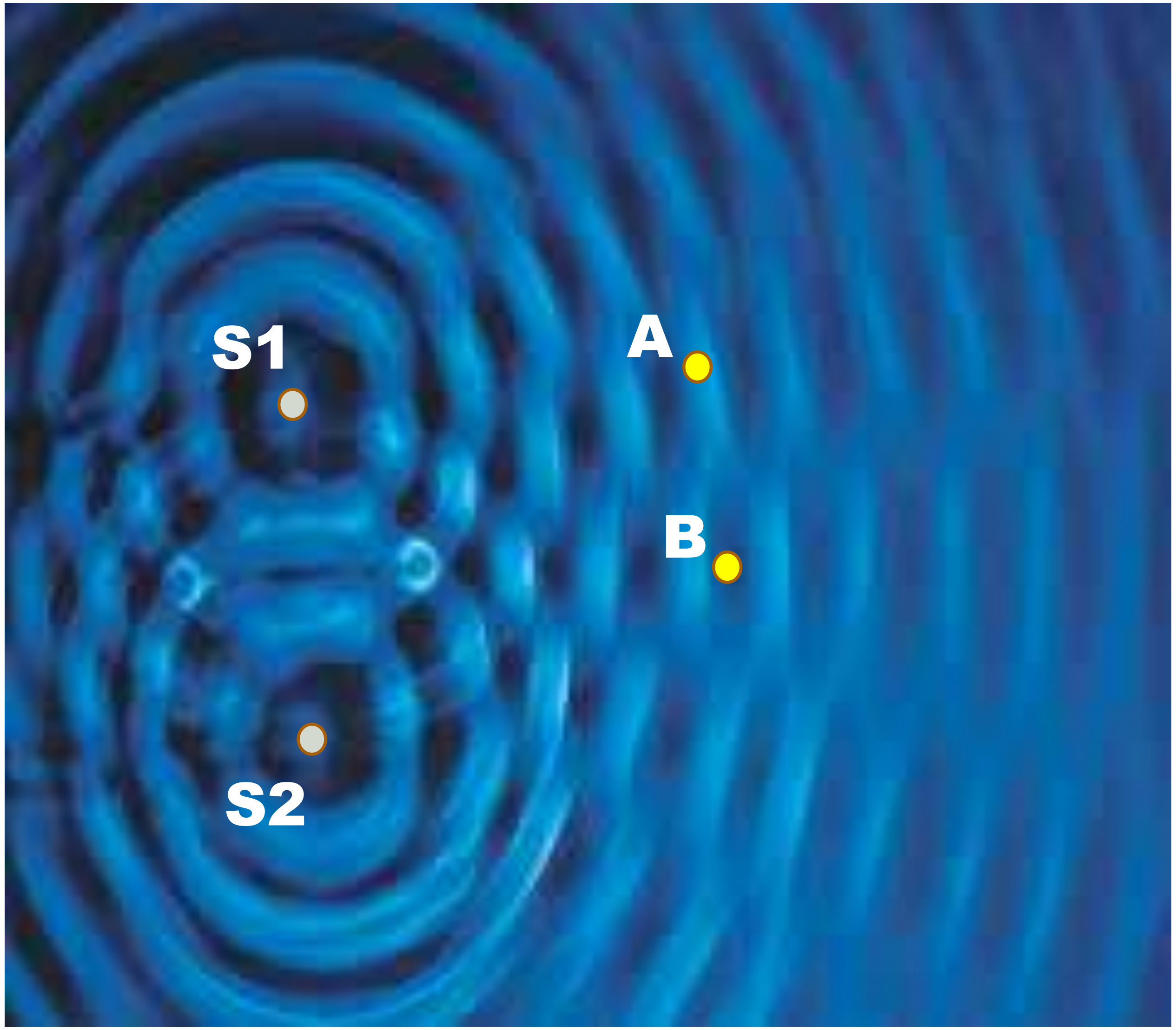
Constructive interference occurs at point ***P*** when the waves combine.

Constructive interference also occurs at point ***Q***

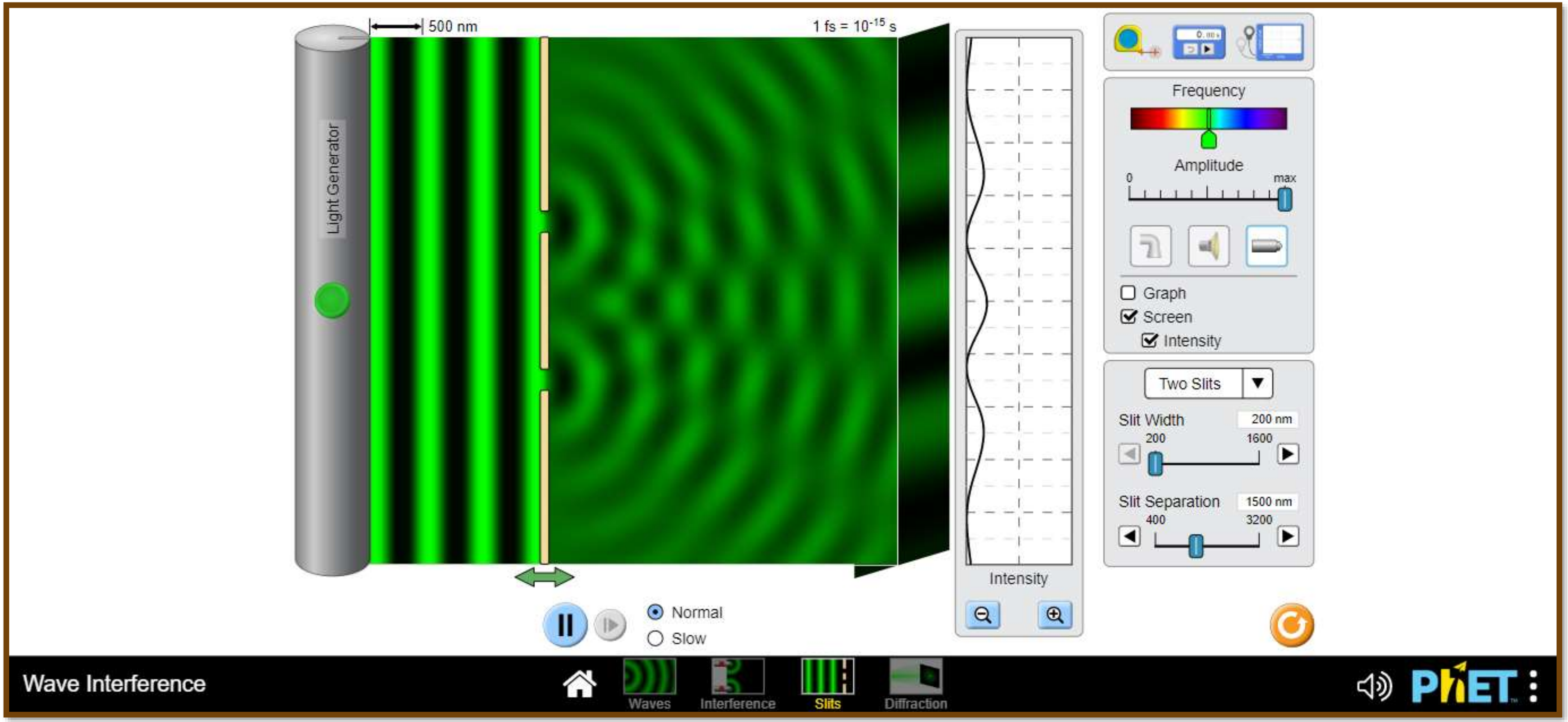
Destructive interference occurs at ***R*** when the two waves combine destructively

Mechanical Analog of double slit experiment

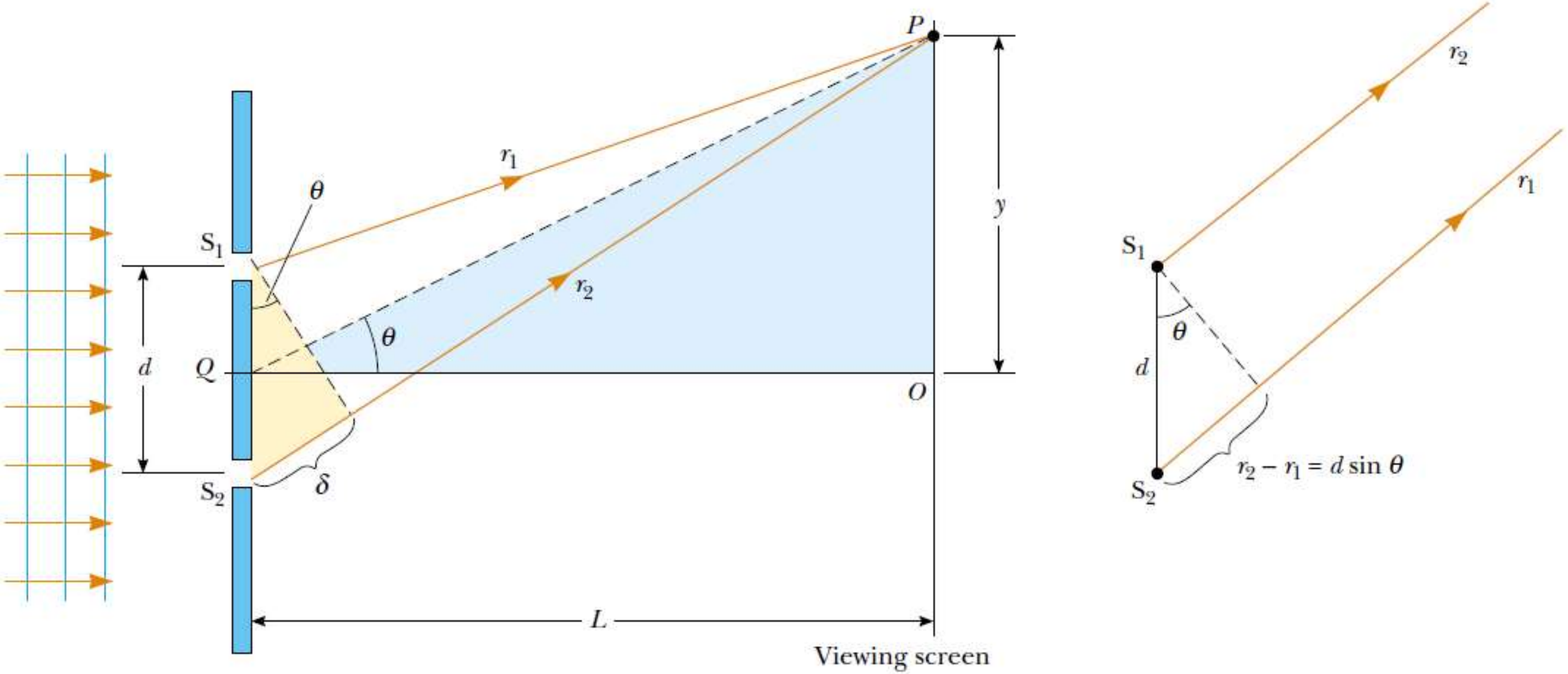
- An interference pattern involving water waves is produced by two vibrating sources at the water's surface (S1 ad S2).
- The pattern is analogous to thatobserved in Young's double-slit experiment.
- Note the regions of constructive (A) and destructive (B) interference.



INTERACTIVE PRESENTATION



Double Slit Experiment: Optical Path Difference

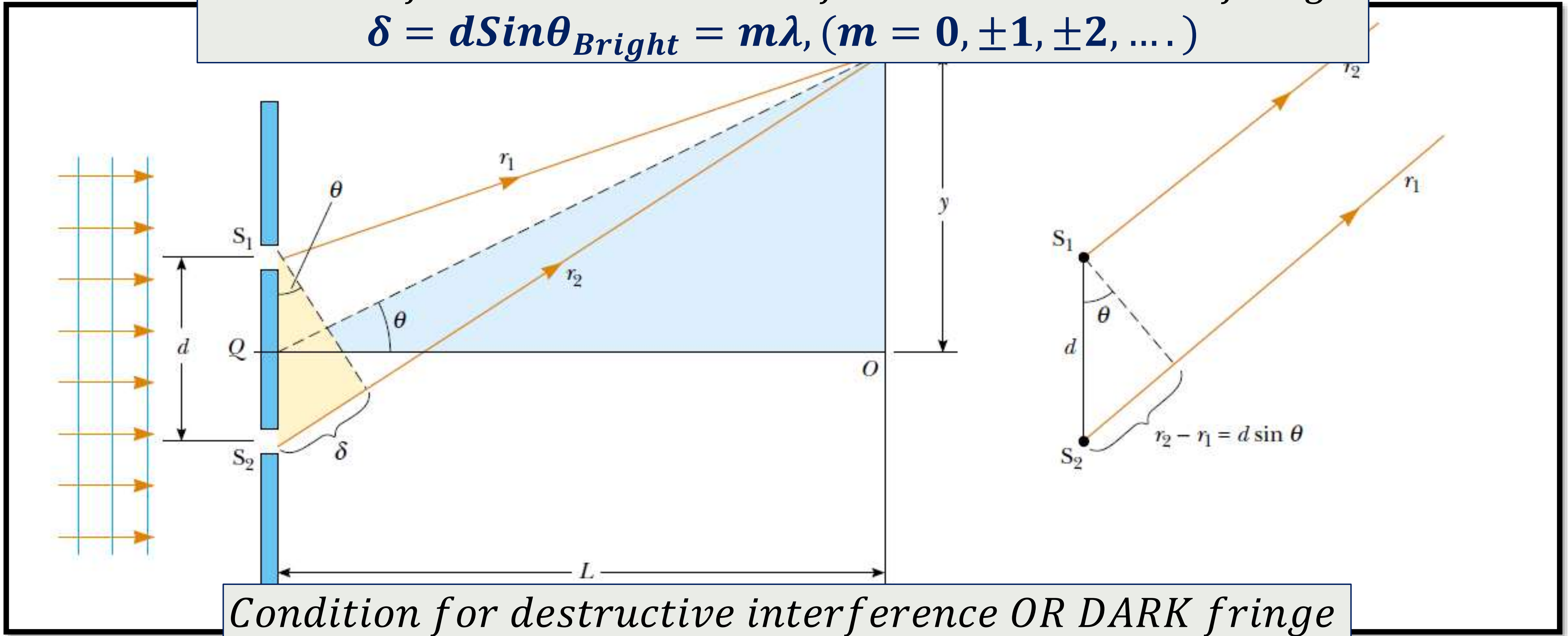


$If, L \gg d, r_1$ and r_2 are $parallel$ to $each$ $other$ and $\boldsymbol{\delta \equiv r_2 - r_2 = d\, Sin\theta}$

Double Slit Experiment – FRINGES

$$Condition\ for\ contructive\ interference\ OR\ BRIGHT\ fringe$$

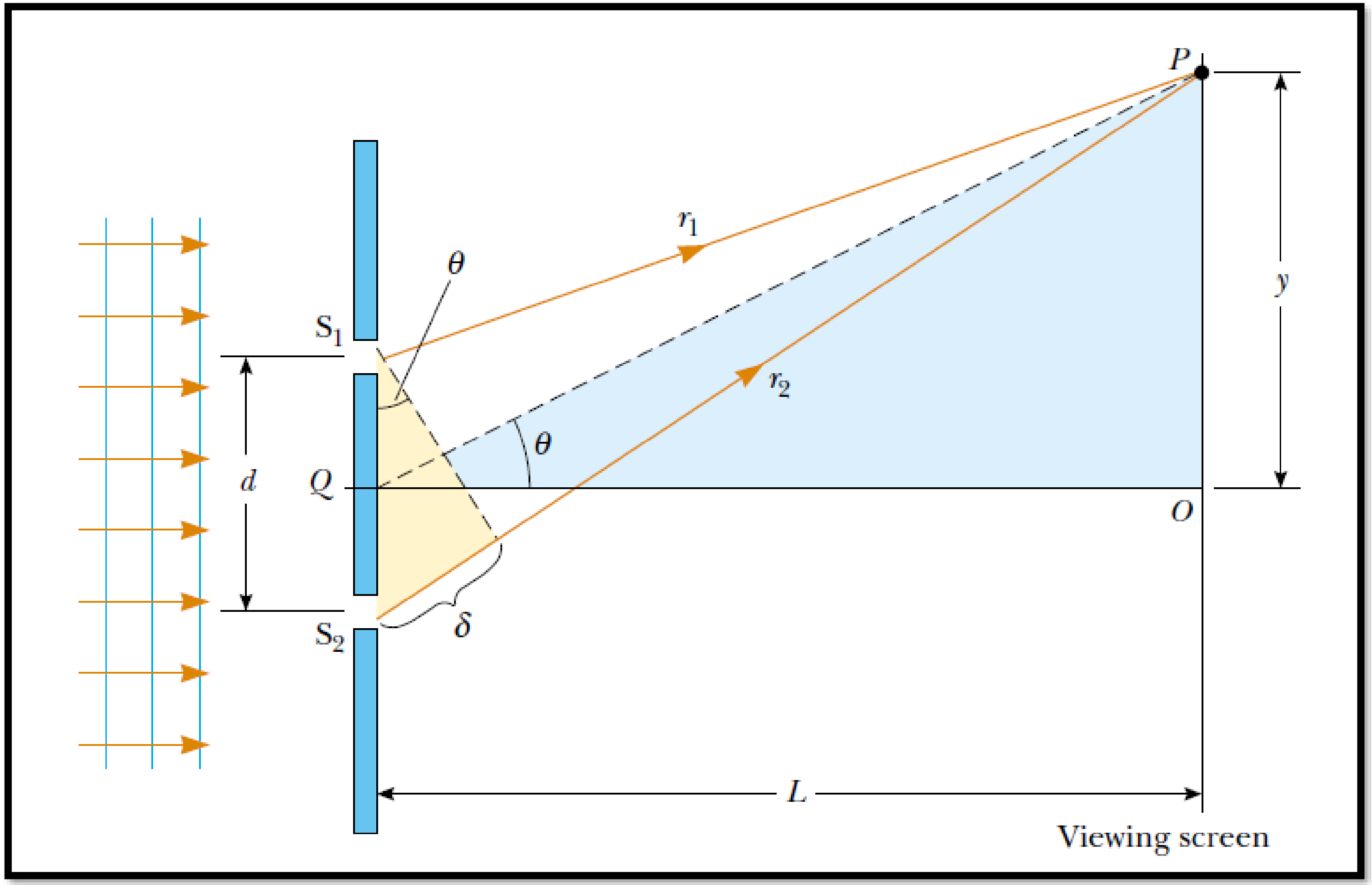
$$\boldsymbol{\delta = dSin\theta_{Bright} = m\lambda, (m = 0, \pm 1, \pm 2, \ldots .)}$$



$$Condition\ for\ destructive\ interference\ OR\ DARK\ fringe$$

$$\boldsymbol{\delta = dSin\theta_{Dark} = \left(m + \frac{1}{2}\right)\lambda, (m = 0, \pm 1, \pm 2, \ldots .)}$$

Double Slit Experiment – FRINGES



For small θ approximation

$$\Rightarrow Sin\theta \approx tan\theta$$

$$\boldsymbol{y = L\ tan\theta \approx LSin\theta}$$

$$\boldsymbol{y_{Bright} = \frac{\lambda L}{d} m}$$

$$\boldsymbol{y_{Dark} = \frac{\lambda L}{d}\left(m + \frac{1}{2}\right)}$$

$$(m = 0, \pm 1, \pm 2, \dots .)$$

POLL QUESTIONS

PROBLEM 1: A viewing screen is separated from a double-slit source by 1.2 m. The distance between the two slits is 0.030 mm. The second-order bright fringe (m = 2) is 4.5 cm from the center line.

i. Determine the wavelength of the light.

$$y_{Bright} = \frac{\lambda L}{d} m$$

A. $\lambda = 480nm$

B. $\lambda = 320nm$

C. $\lambda = 560nm$

D. $\lambda = 610nm$

What is the associated color?

POLL QUESTIONS

PROBLEM 1: A viewing screen is separated from a double-slit source by 1.2 m. The distance between the two slits is 0.030 mm. The second-order bright fringe (m = 2) is 4.5 cm from the center line.

$$y_{Bright} = \frac{\lambda L}{d} m$$

i. Calculate the distance between adjacent bright fringes.

A. 4.1 cm

B. 2.2 cm

C. 4.4 cm

D. 5.6 cm

POLL QUESTIONS

PROBLEM 2 A light source emits visible light of two wavelengths: $\lambda_1 = 430$ nm and & $\lambda_2 = 510$ nm. The source is used in a double-slit interference experiment in which L = 1.50 m and d = 0.025 mm.

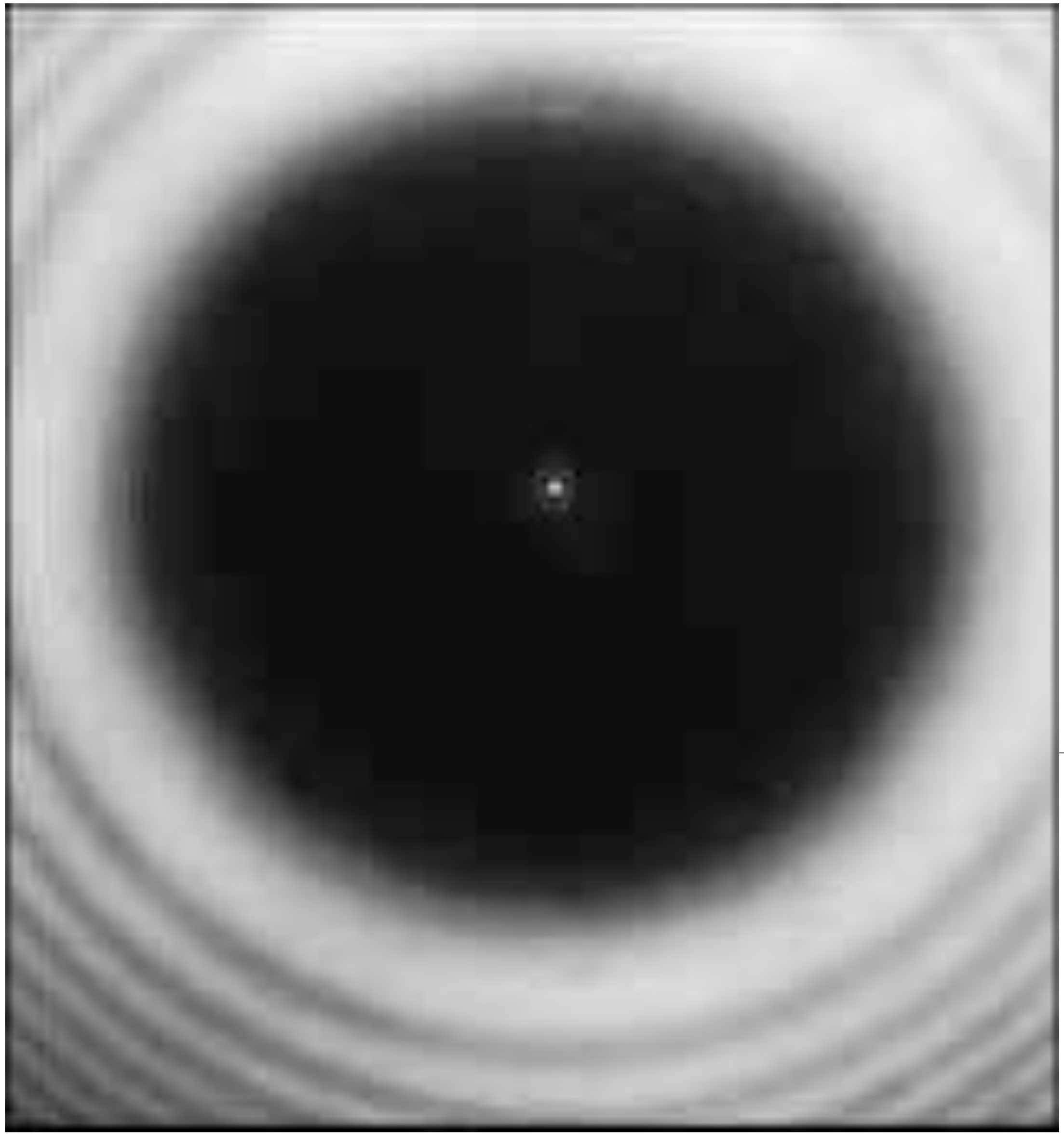
i. Find the separation distance between the third-order bright fringes.

A. 3.40 cm

B. 1.40cm

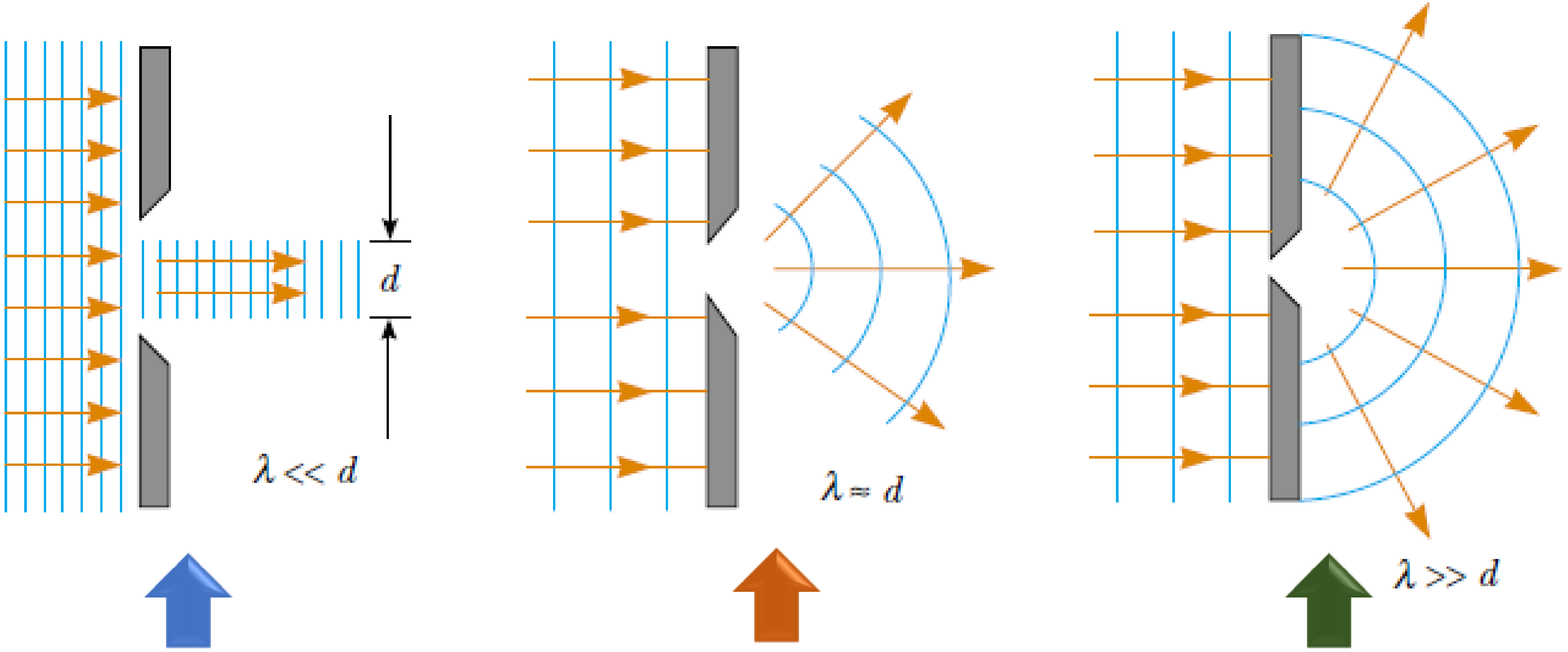
C. 2.40 cm

D. 4.80 cm



WAVE OPTICS II: *DIFFRACTION*

Diffraction as a Concept

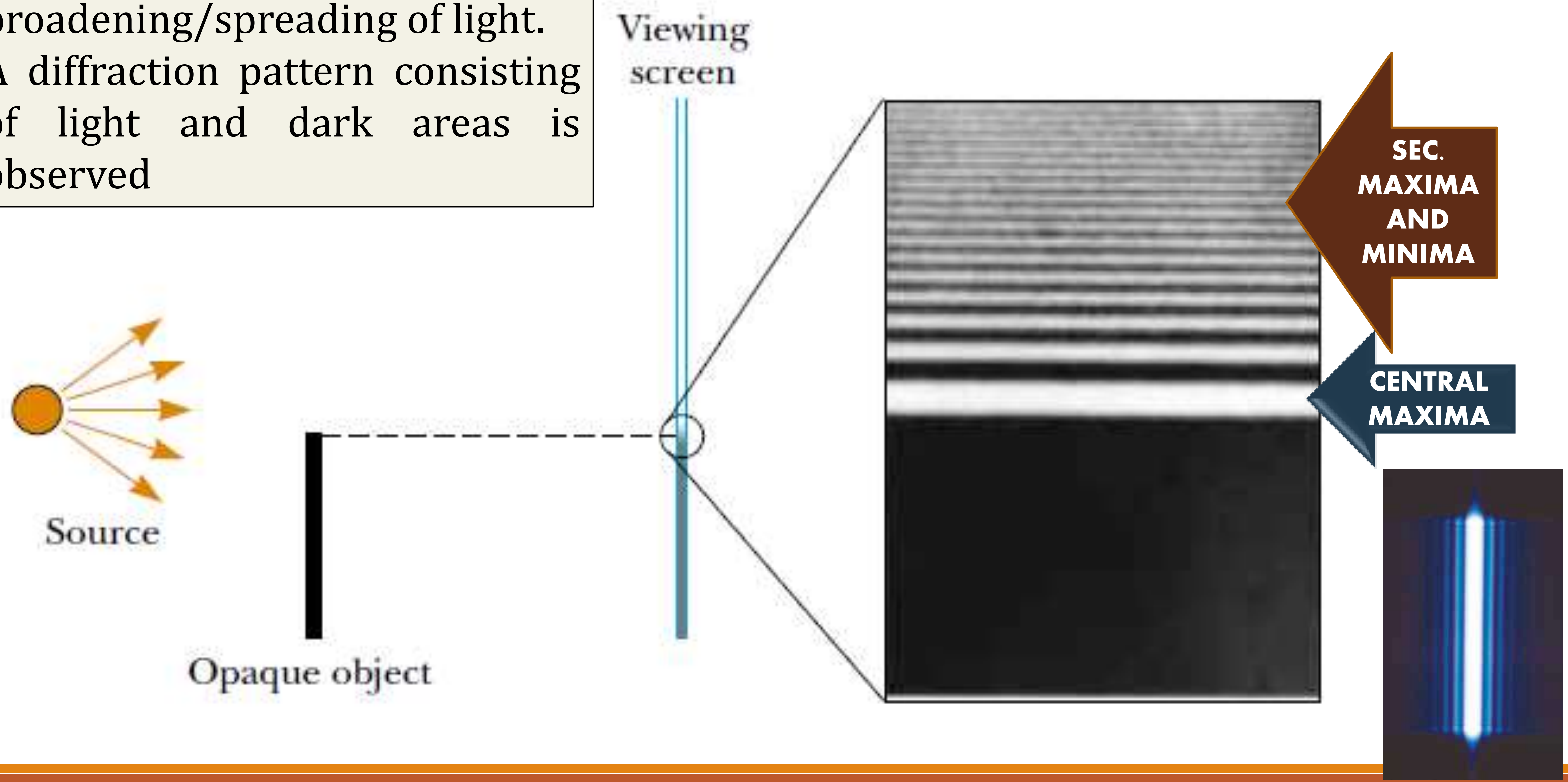


the rays continue in a straight-line path, and the ray approximation is valid

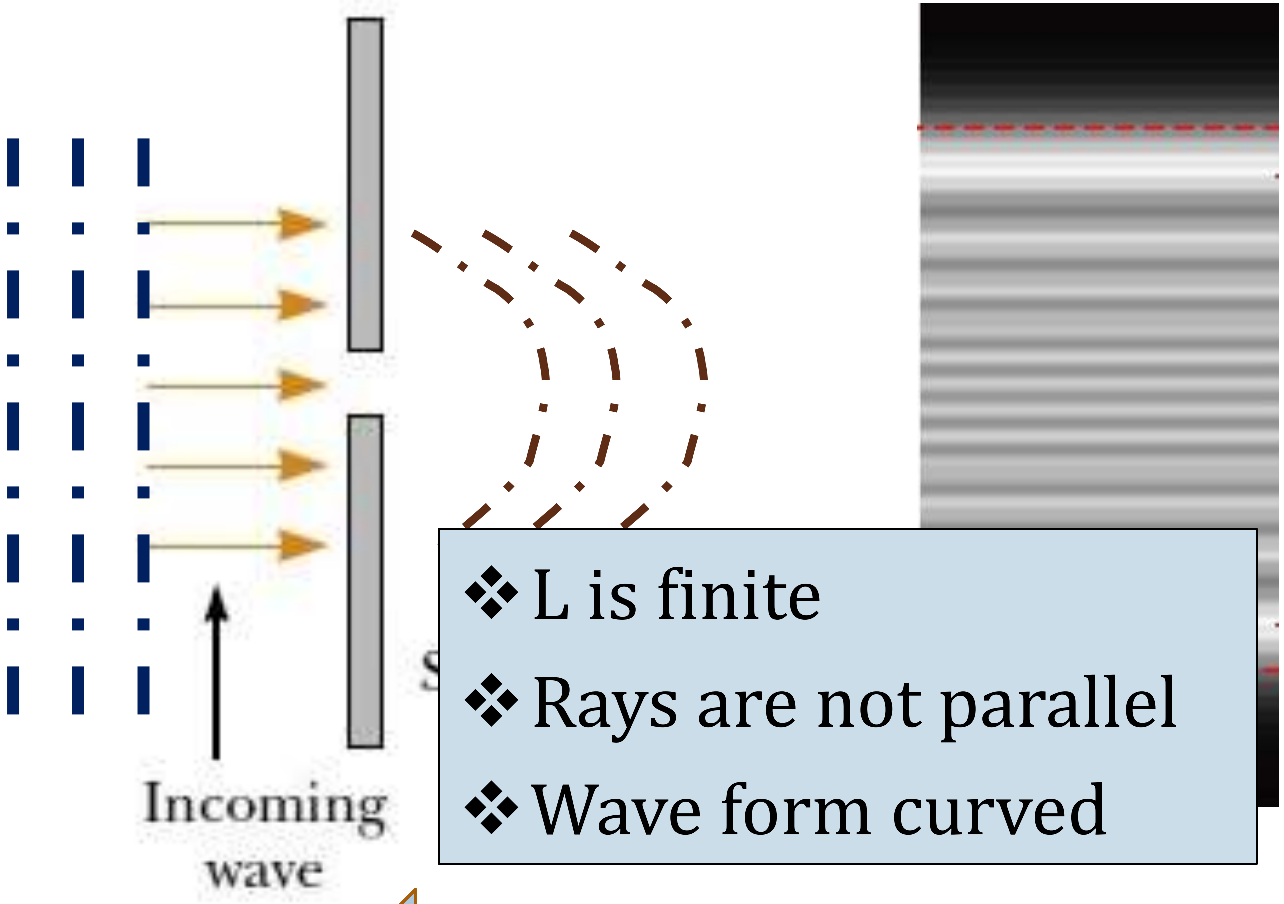
the rays spread out after passing through the opening - ***DIFFRACTION***

the opening behaves as a point source emitting spherical waves.

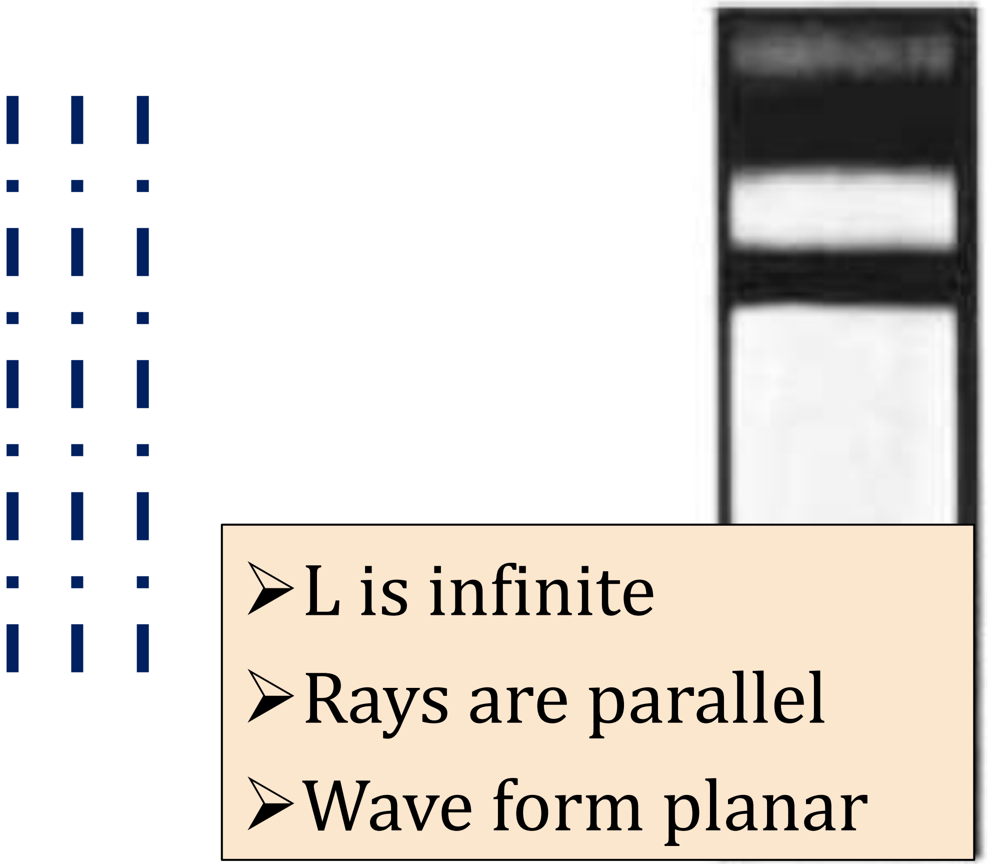
- This is not simple broadening/spreading of light.
- A diffraction pattern consisting of light and dark areas is observed



Types of Diffraction



- ❖ L is finite
- ❖ Rays are not parallel
- ❖ Wave form curved

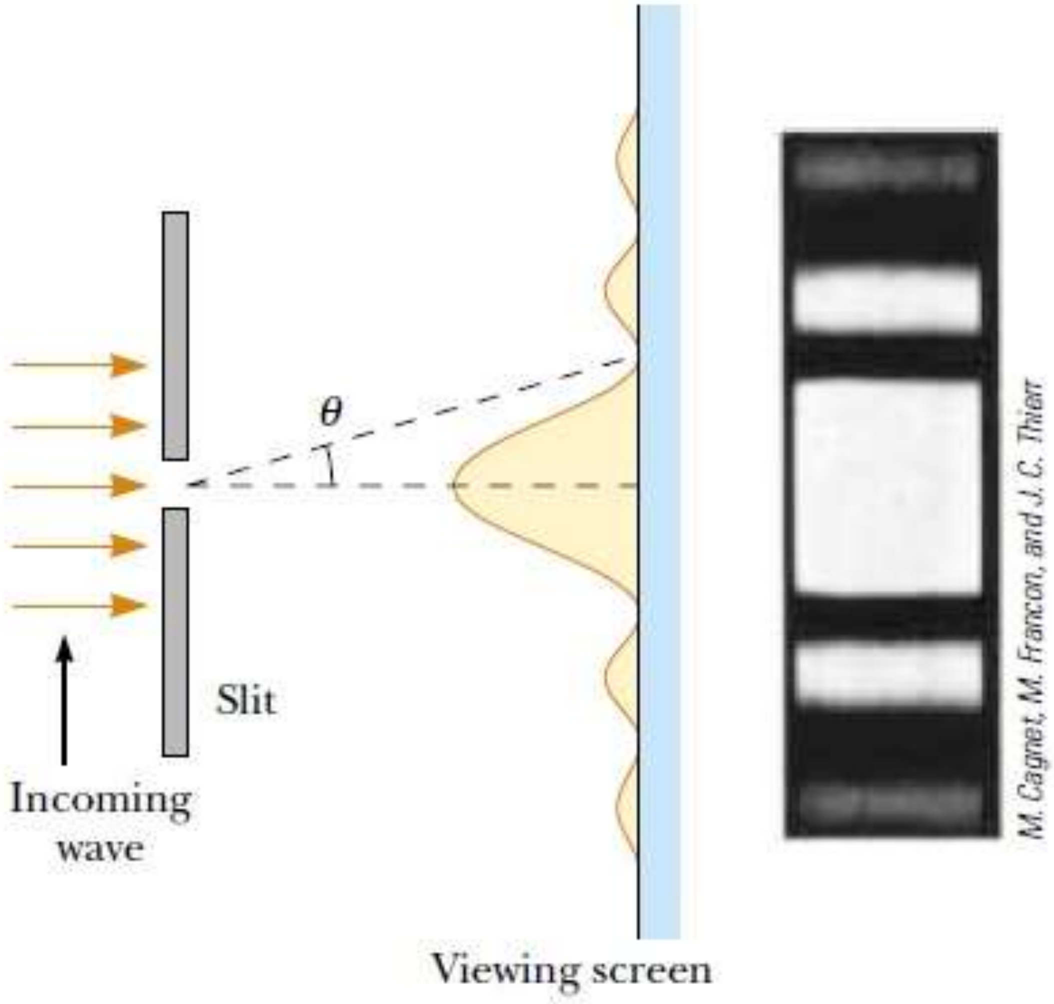


- ➤ L is infinite
- ➤ Rays are parallel
- ➤ Wave form planar

FRESNEL REGION

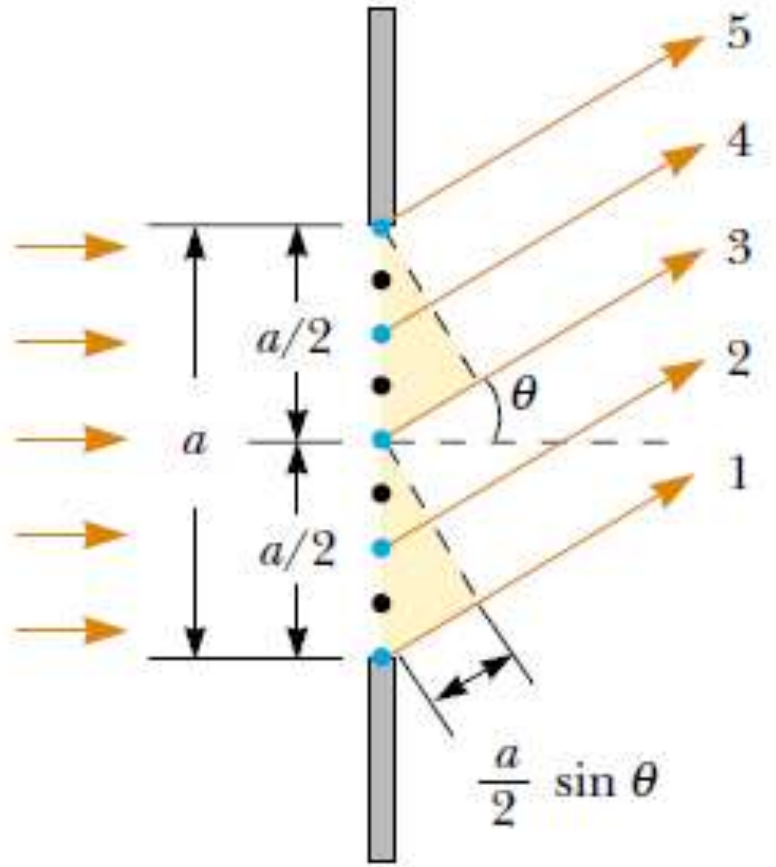
FRAUNHOFER REGION

Fraunhofer Diffraction



- For simplicity of the understanding, we will limit ourselves into Fraunhofer Diffraction regime.
- Now we need to abandon the assumption that slits are point source of light.
- The finite width of slits will be the basis for understanding Fraunhofer diffraction.
- According to Huygens's principle, each portion of the slit acts as a source of light waves.
- Hence, light from one portion of the slit can interfere with light from another portion,
- and the resultant light intensity on a viewing screen depends on the direction.
- So, *we can recognize that a diffraction pattern is actually an interference pattern*.

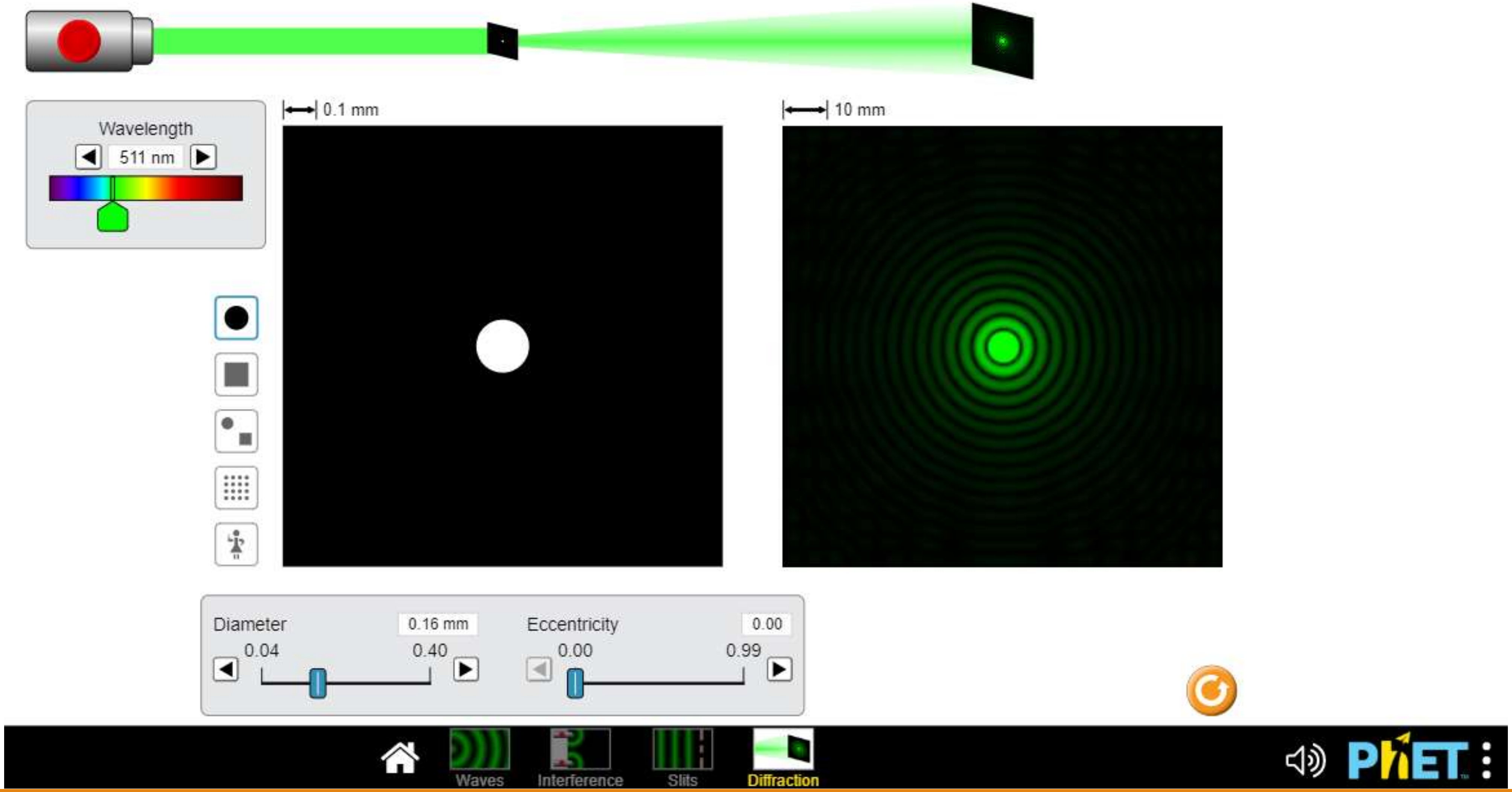
Fraunhofer Diffraction: Origin of Dark Spots



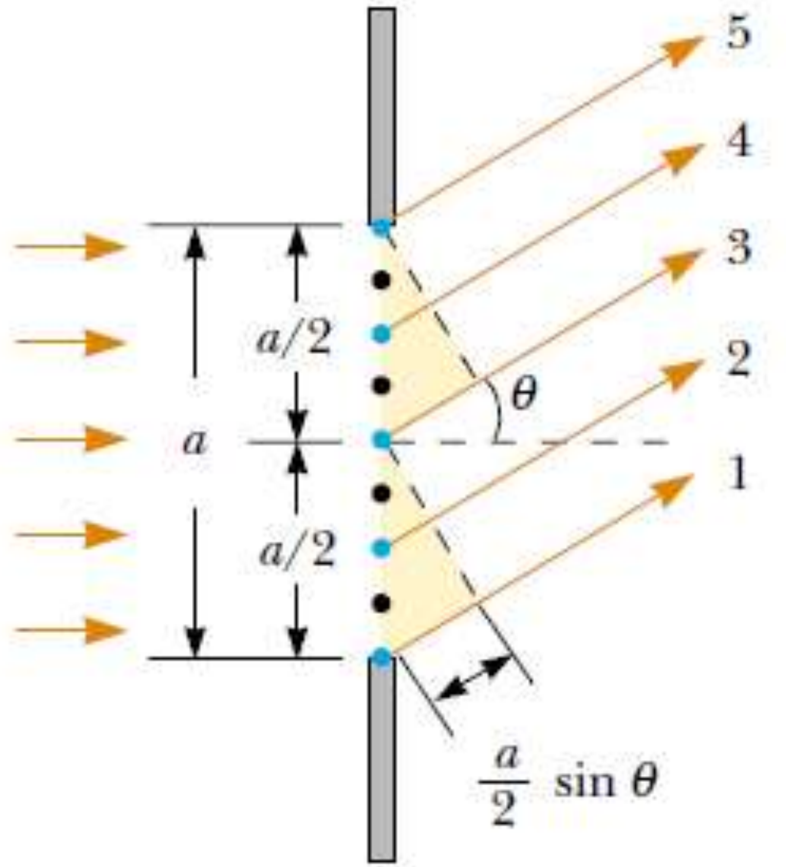
- To analyze the diffraction pattern, it is convenient to divide the slit into two halves.
- Keeping in mind that all the waves are in phase as they leave the slit, consider rays 1 and 3 As these two rays travel toward a viewing screen far to the right of the figure.
- The path difference $\delta \equiv ray_3 - ray_1 = \frac{a}{2}sin\theta$
- Also, similarly $\delta \equiv ray_4 - ray_2 \equiv ray_5 - ray_3 = \frac{a}{2}sin\theta$
- If this path difference is exactly half a wavelength (corresponding to a phase difference of 180°), then the two waves cancel each other and destructive interference results:

$$\frac{a}{2}sin\theta = \pm\frac{\lambda}{2}$$

INTERACTIVE PRESENTATION



Fraunhofer Diffraction: Origin of Dark Spots



- By further imagination we can divide the single slit area into four equal regions where compete destructive interference would require:

$$\frac{a}{2}sin\theta = \pm 2\frac{\lambda}{2}$$

- If we divide into six equal regions, complete destructive interference will require:

$$\frac{a}{2}sin\theta = \pm 3\frac{\lambda}{2}$$

- **AND SO ON.**
- **A general formula for destructive interference can be:**

$$\boldsymbol{\frac{a}{2}sin\theta_{Dark} = \pm m\frac{\lambda}{2}, (m = \pm 1, \pm 2, \pm 3, \dots)}$$

POLL QUESTIONS

Light of wavelength 580 nm is incident on a slit having a width of 0.300 mm. The viewing screen is 2.00 m from the slit.

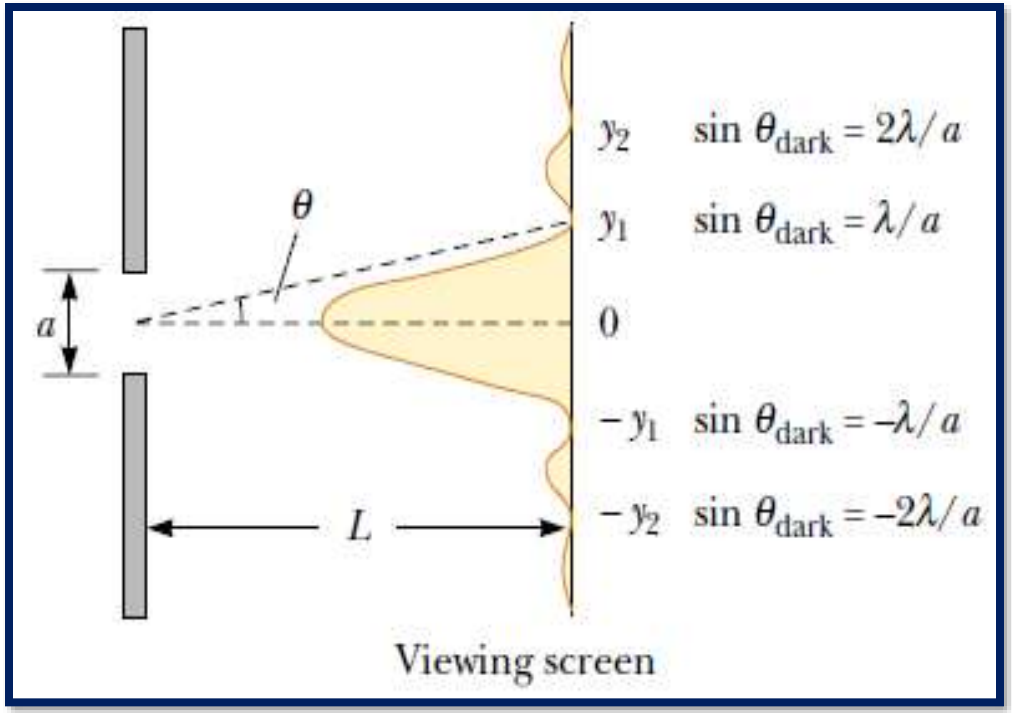
Find the positions of the first dark fringes

A. $\pm 3.87\ mm$

B. $\pm 2.43\ mm$

C. $\pm 1.88\ mm$

D. $\pm 6.67\ mm$



USE HINT FROM THE IMAGE: RELATION BETWEEN y & L

POLL QUESTIONS

Light of wavelength 580 nm is incident on a slit having a width of 0.300 mm. The viewing screen is 2.00 m from the slit.

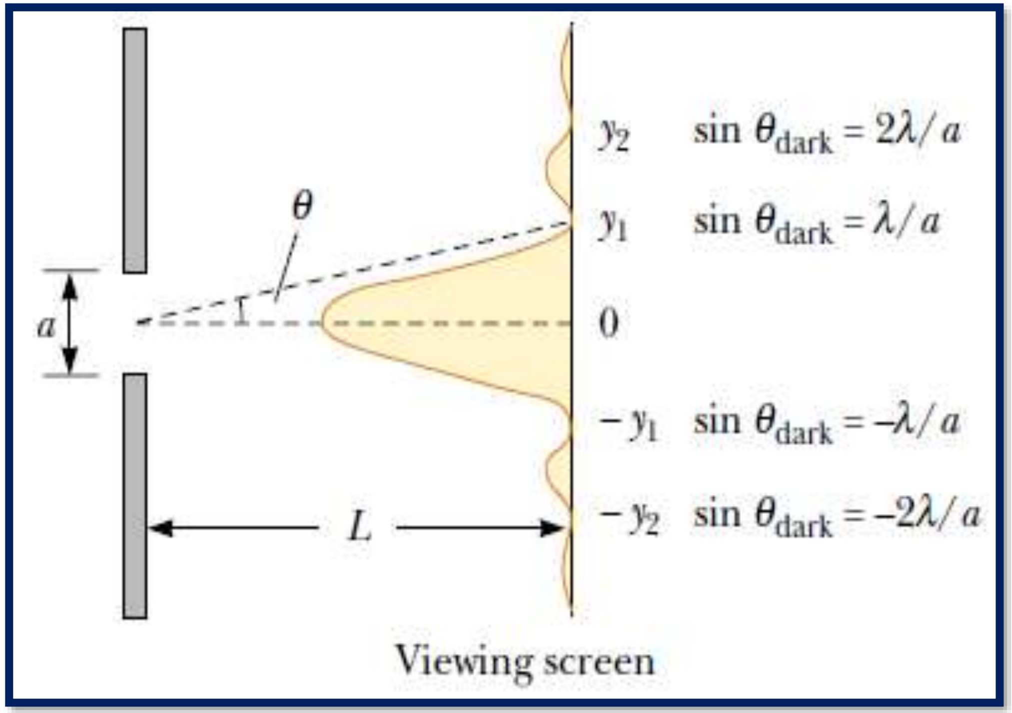
Find the width of the central bright fringe.

A. 3.87 *mm*

B. 6.60 *mm*

C. 7.74 *mm*

D. 5.21 *mm*



USE HINT FROM THE IMAGE: RELATION BETWEEN y & L

POLL QUESTIONS

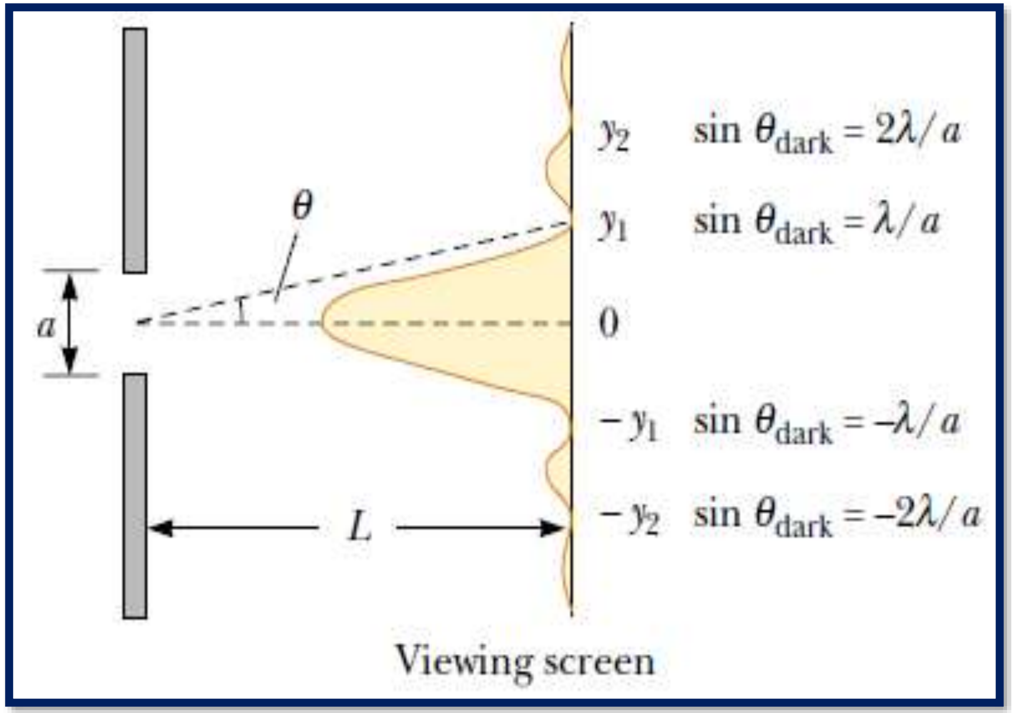
Light of wavelength 580 nm is incident on a slit having a width of 0.300 mm. The viewing screen is 2.00 m from the slit. Recalculate the position of the width of the central bright fringe if is increased by an order of magnitude to 3.00 mm.

A. 0.0774 *mm*

B. 77.4 *mm*

C. 7.74 *mm*

D. 0.774 *mm*



USE HINT FROM THE IMAGE:
RELATION BETWEEN y & L