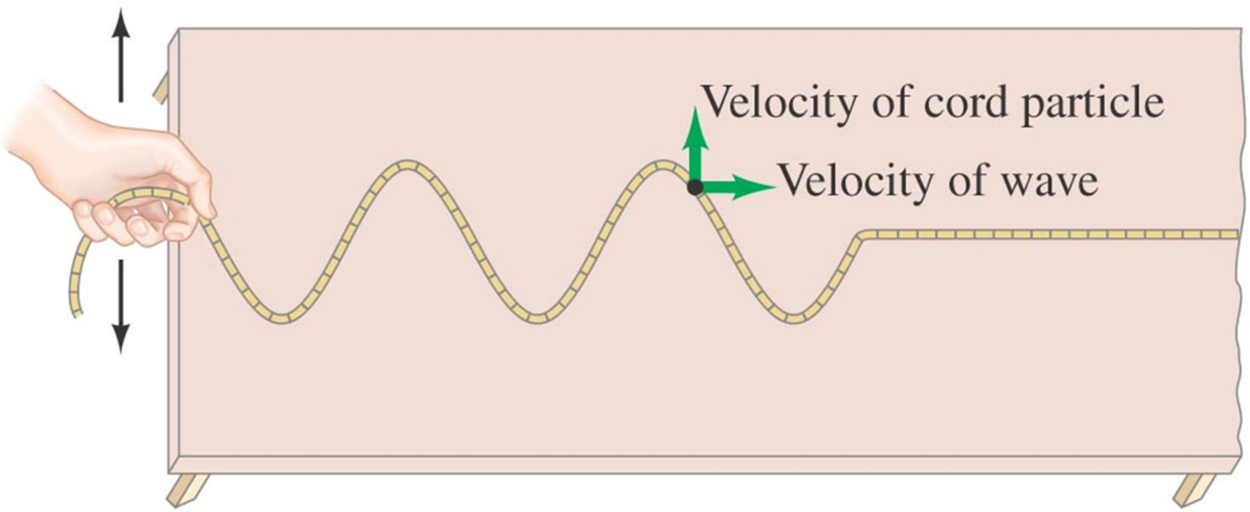
Waves 1120

Waves

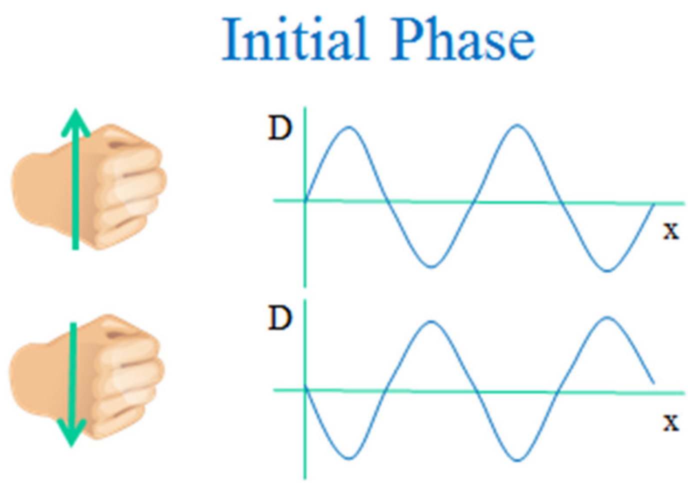


- Average speed of cord particle is zero, just moves up and down.
- We are interested in wave velocity
- Waves carry energy, momentum, but not mass

Demo

- http://phet.colorado.edu/sims/wave-on-a-string/wave-on-a-string_en.html

- Oscillator (person or machine) controls *A* and *f* and initial phase



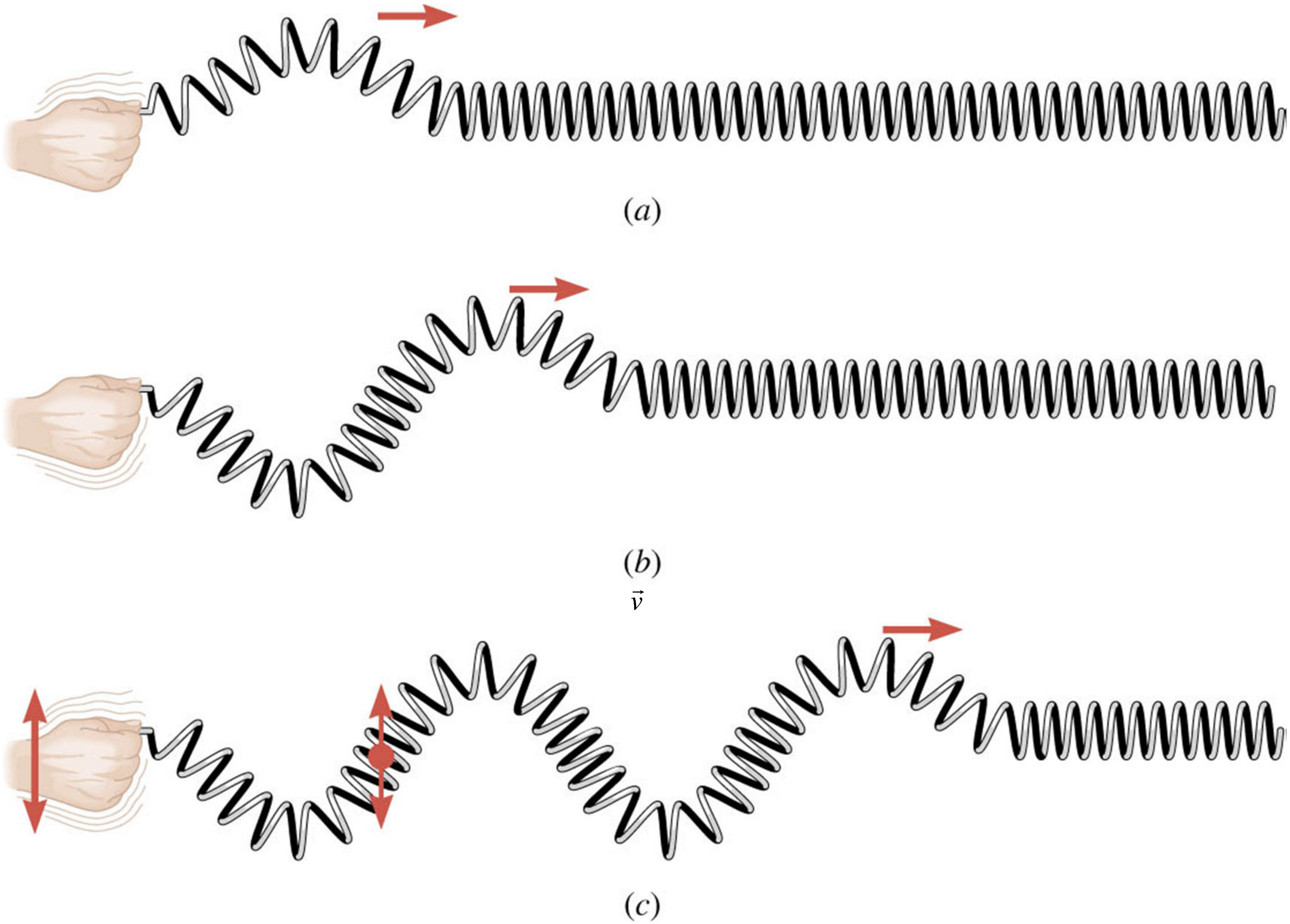
You can start off equilibrium to get any initial phase constant you want.

- Speed *v* depends on medium and is independent of *A* and *f*

$$v_{string} = \sqrt{\frac{Tension}{mass/length}}$$

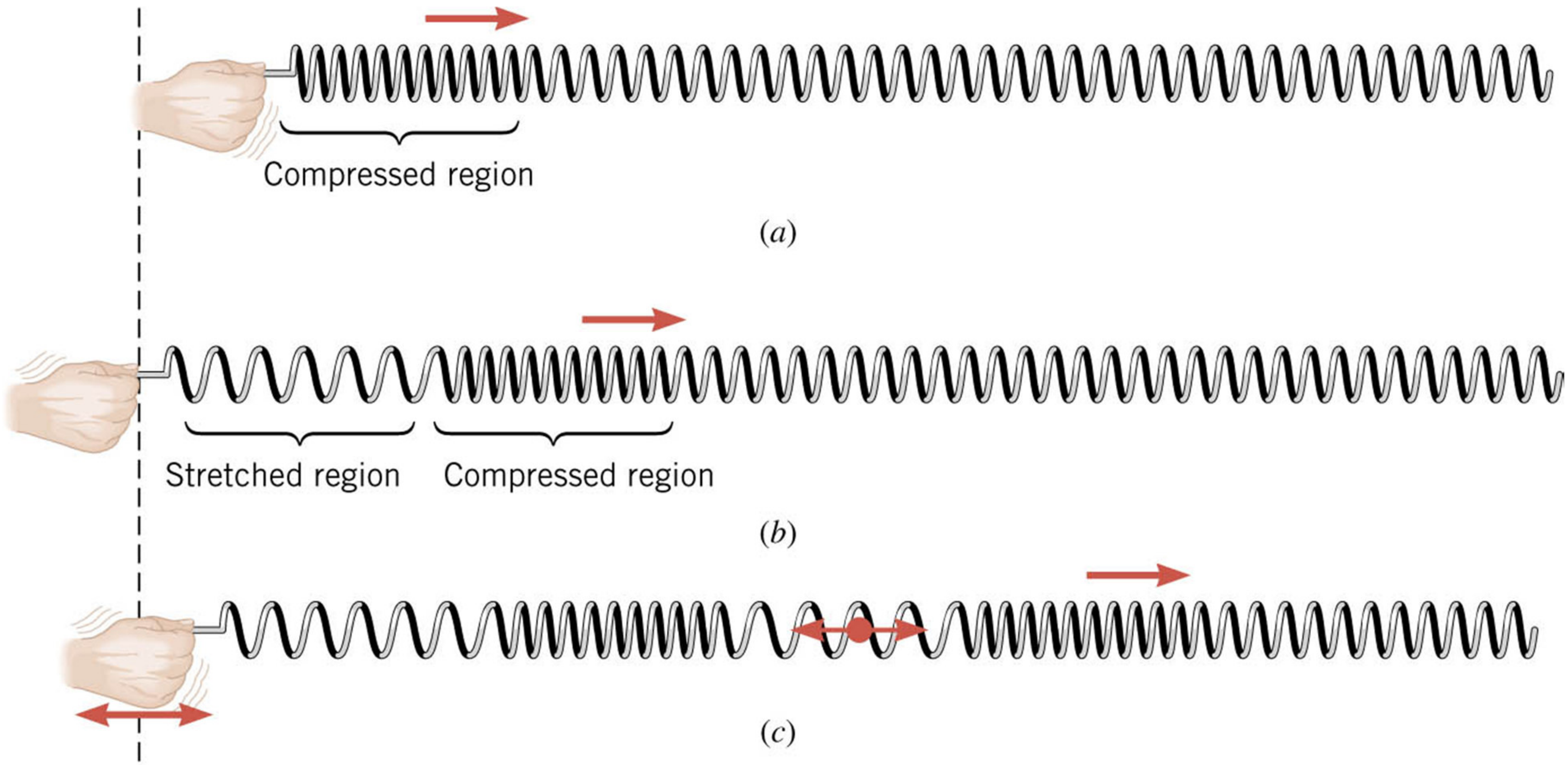
$\mu = \frac{mass}{length}$ linear density

v_{air} = 340 m/s but varies with temperature and pressure.



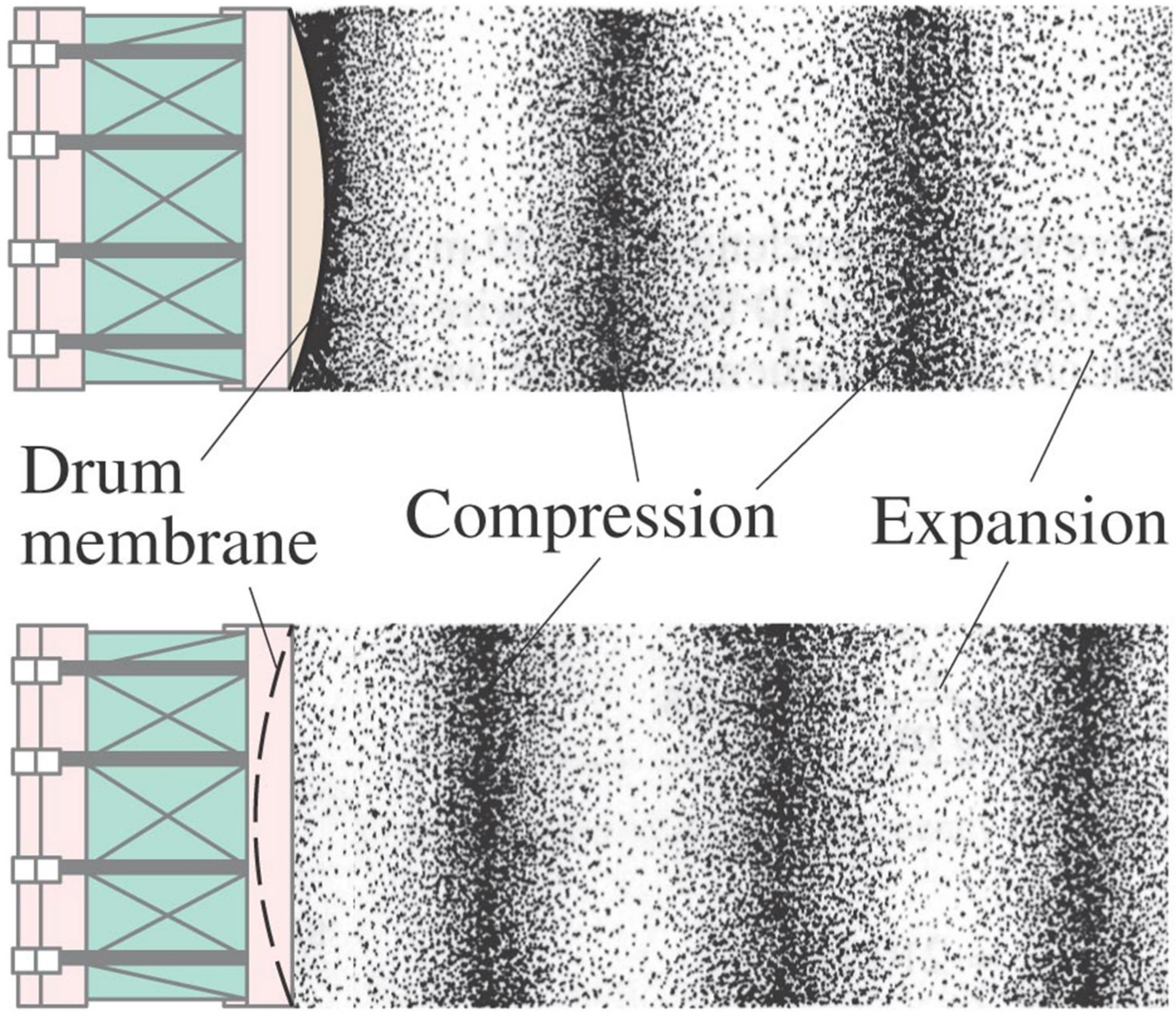
Transverse Wave

Disturbance $\perp \vec{v}$

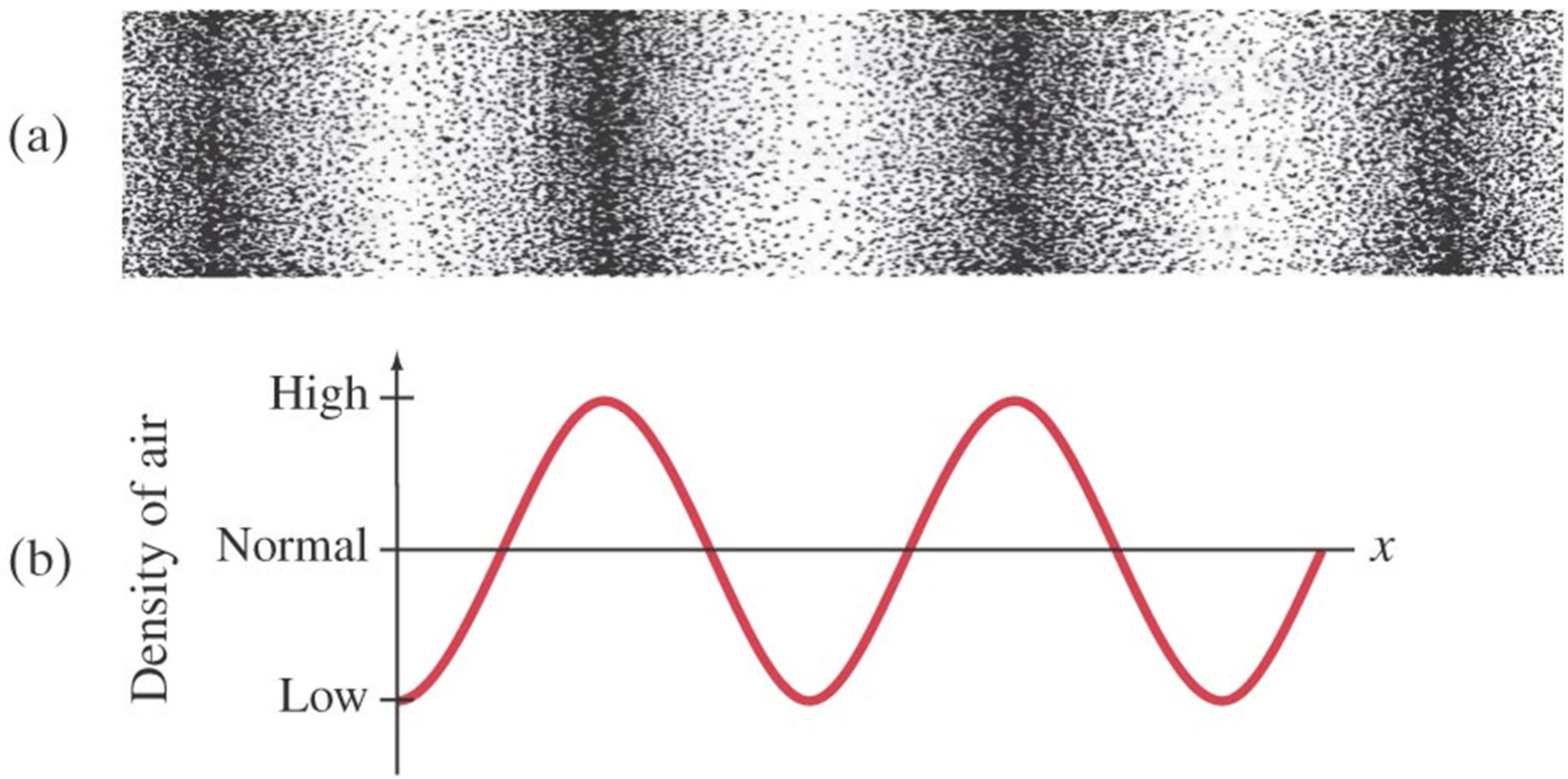


Longitudinal Wave

Disturbance || $\vec{v}$

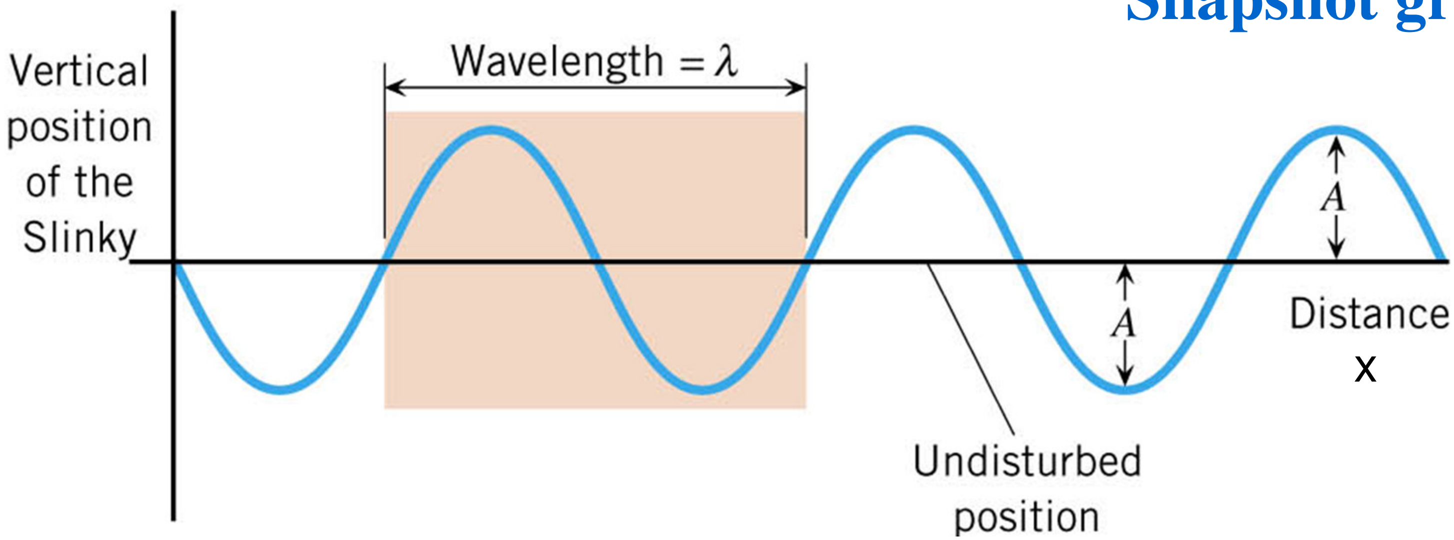


Sound – Air is compressed/rarefied



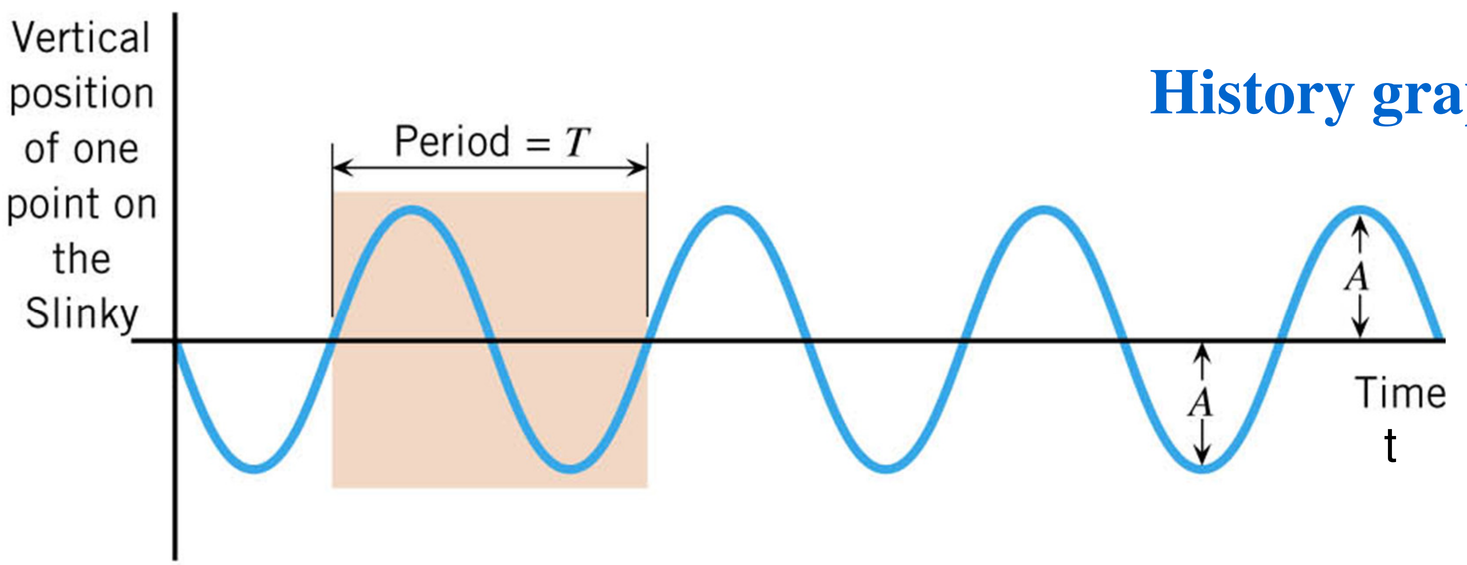
All waves can be described by a sinusoidal curve. The amplitude can be displacement of medium (transverse) or density (longitudinal).

Snapshot graph



At a particular time

History graph



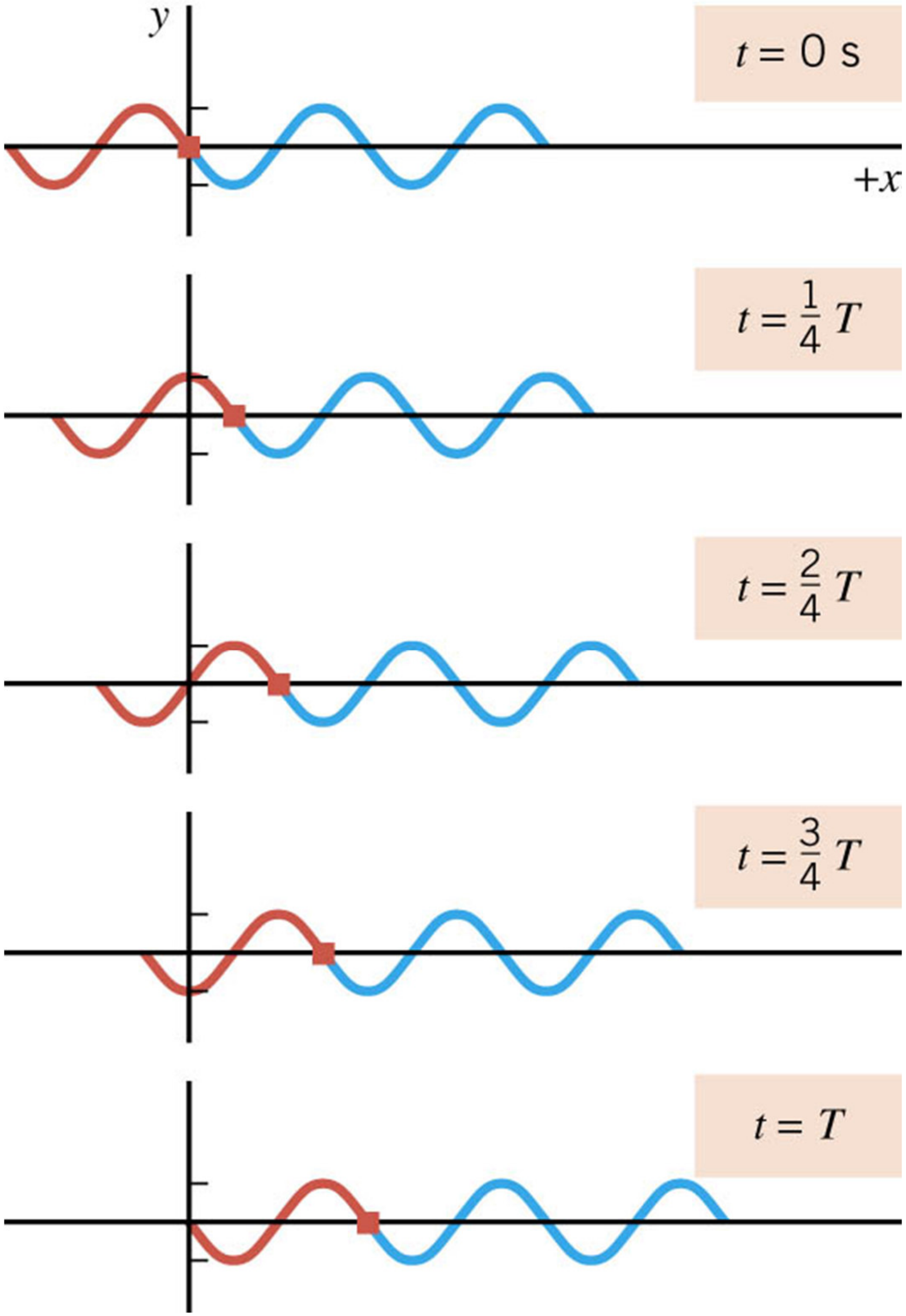
y

At a particular location

Determining k and ω

- Snapshot is periodic in wavelength λ
- $y = A\sin(kx) = A\sin(k[x + \lambda]) \Rightarrow k\lambda = 2\pi$
- k called wavenumber

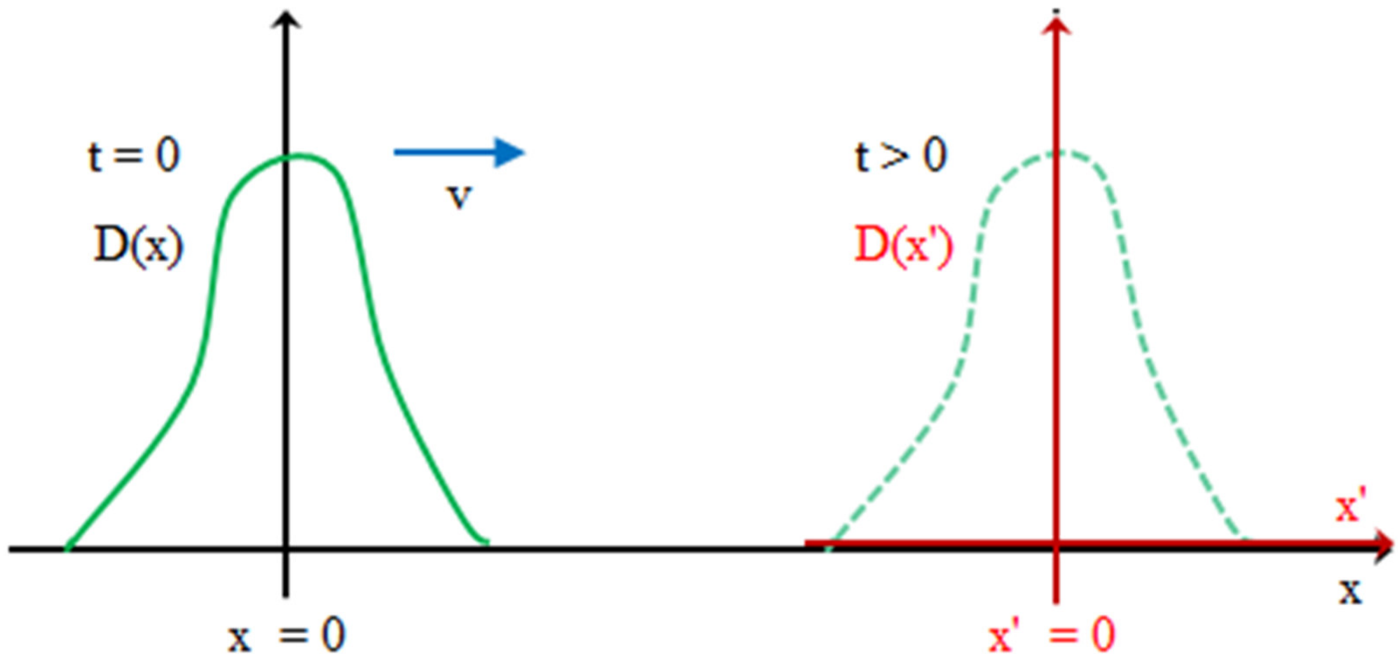
- History is periodic in period T
- $y = A\sin(\omega t) = A\sin(\omega[t + T]) \Rightarrow \omega T = 2\pi$
- ω called angular frequency



In one period T, wave moves one wavelength λ

$v = \lambda/T = \lambda f$

Finding *y*(*x*, *t*) Equation



$$D(x') = A\sin(2\pi x'/\lambda)$$

But $x' = x - vt$ which means $D(x')$ is $D(x, t)$!

$$D(x, t) = A\sin(\ (2\pi/\lambda)(x - vt)\ )$$

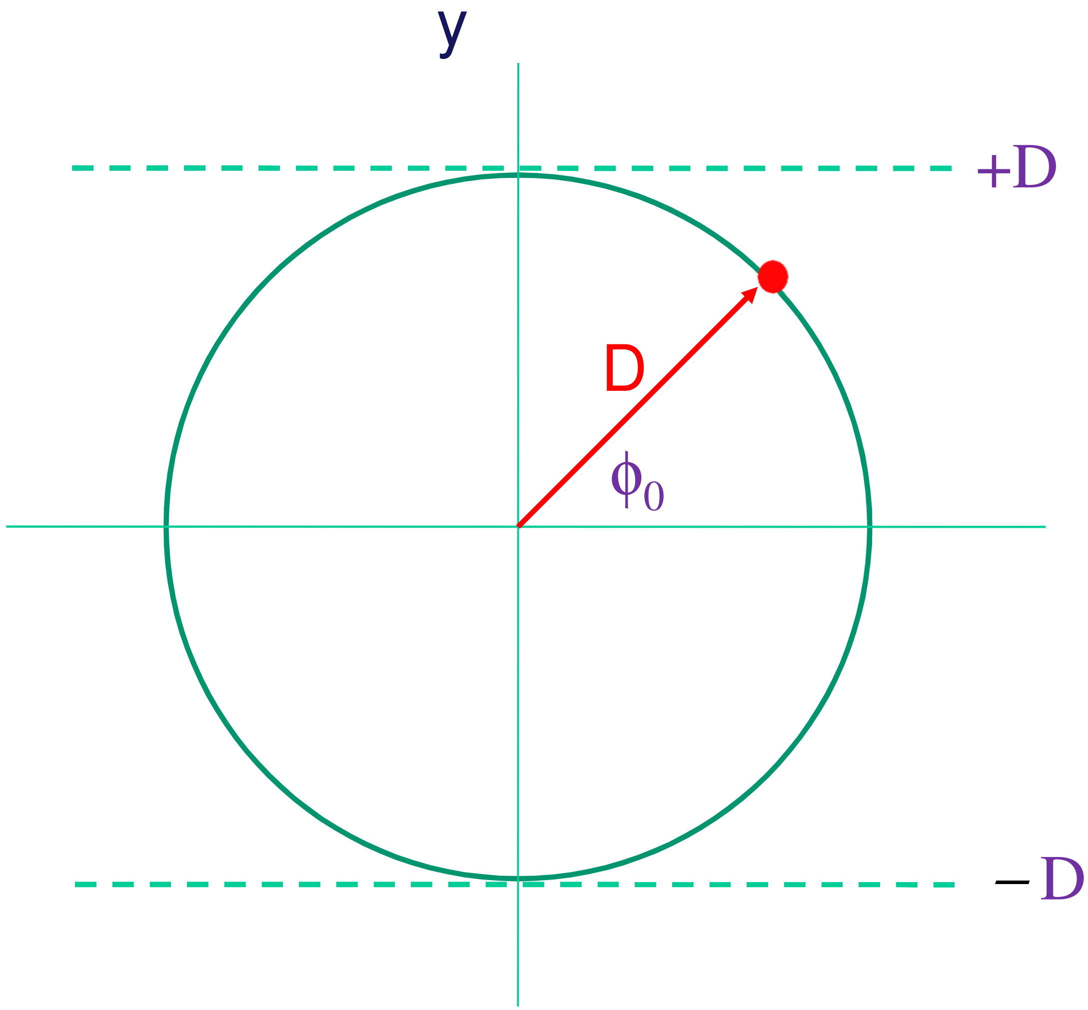
$$D(x, t) = A\sin(\ 2\pi x/\lambda - 2\pi vt/\lambda\ )$$

$$D(x, t) = A\sin(\ 2\pi x/\lambda - 2\pi ft\ )$$

Use + if wave moves left

Reference Circle

t = 0, x = 0 reference circle



Motion of dot depends on direction of wave!

$$y = D\sin(\theta)$$

wave moving right $\rightarrow$ $\theta = kx - \omega t + \phi_0$

if $x\uparrow$, $\theta\uparrow$ (move ccw).
if $t\uparrow$, $\theta\downarrow$ (move cw).

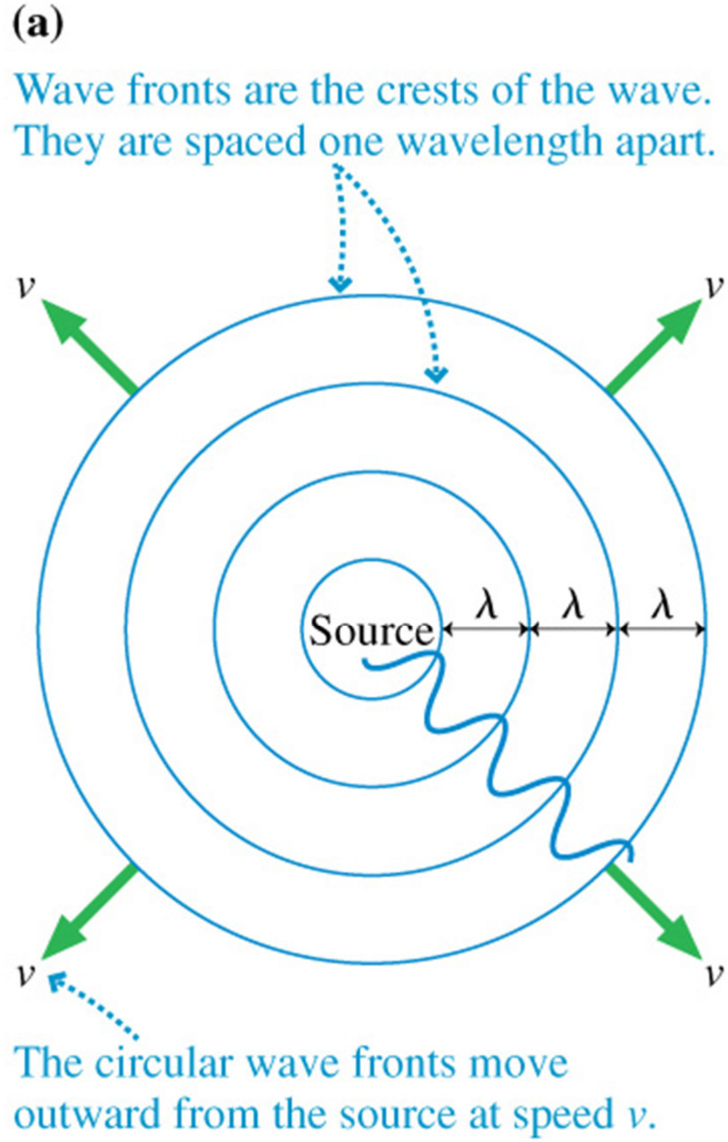
wave moving left $\leftarrow$ $\theta = kx + \omega t + \phi_0$

if $x\uparrow$, $\theta\uparrow$ (move ccw).
if $t\uparrow$, $\theta\uparrow$ (move ccw).

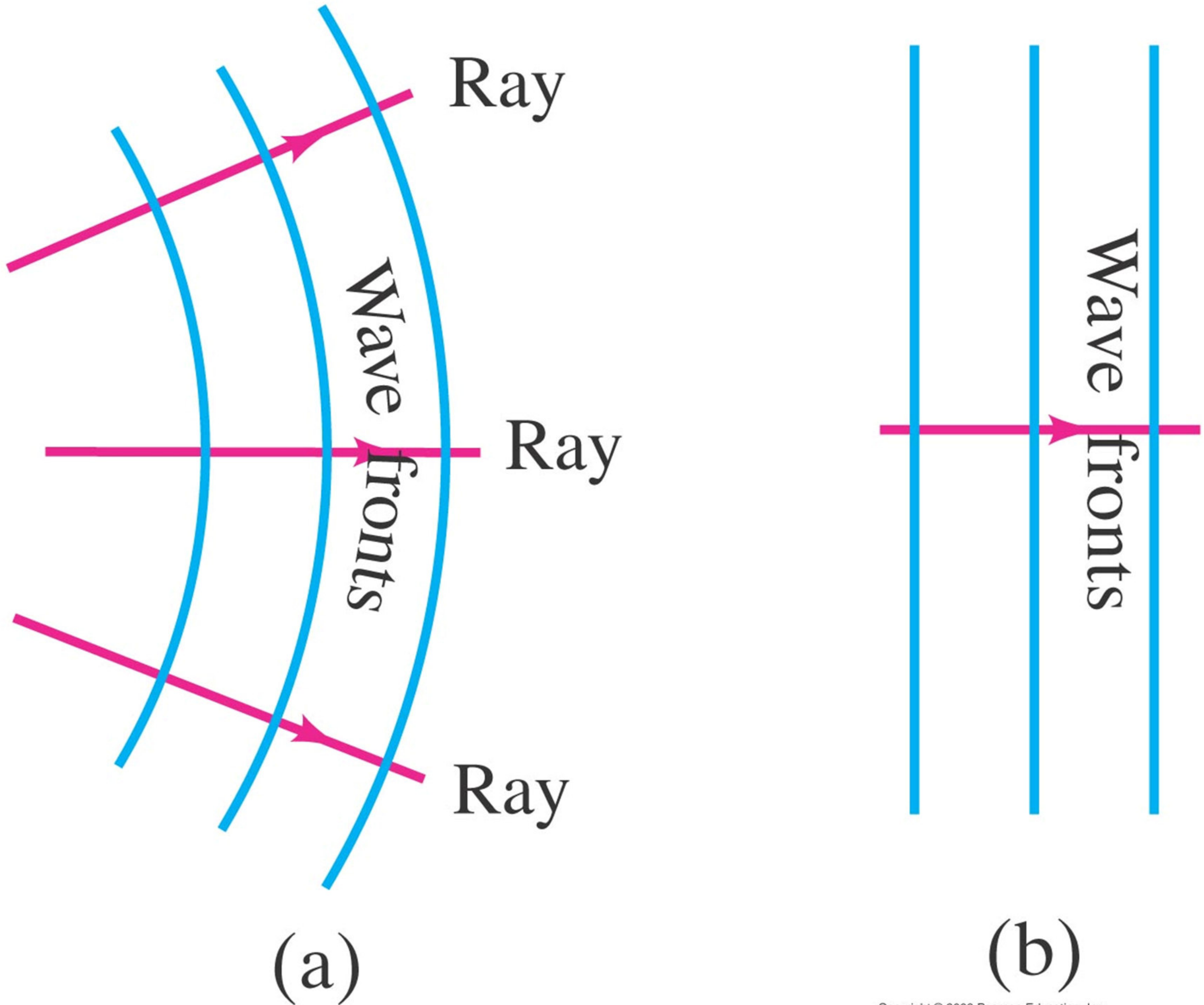
Questions

Waves in 2D and 3D

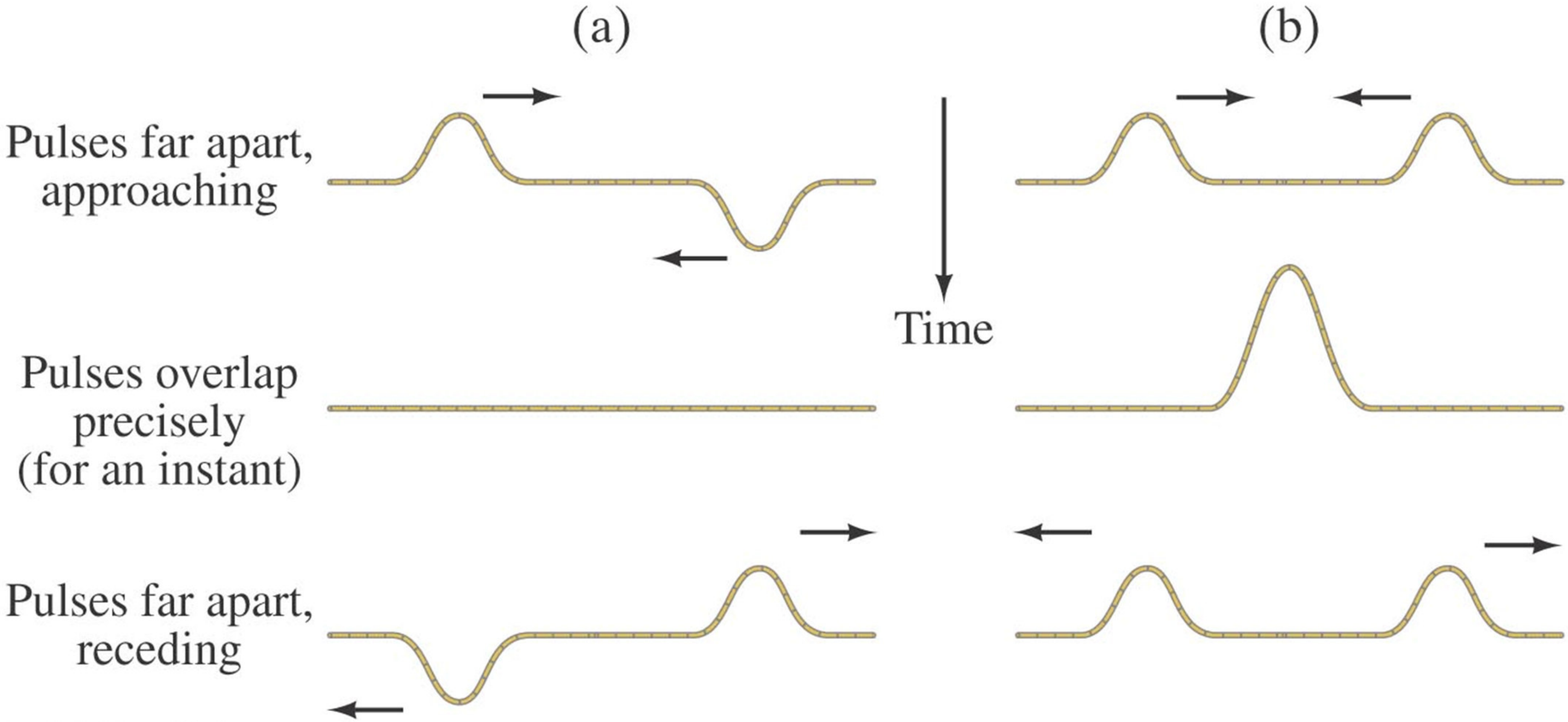
Waves in 2D and 3D

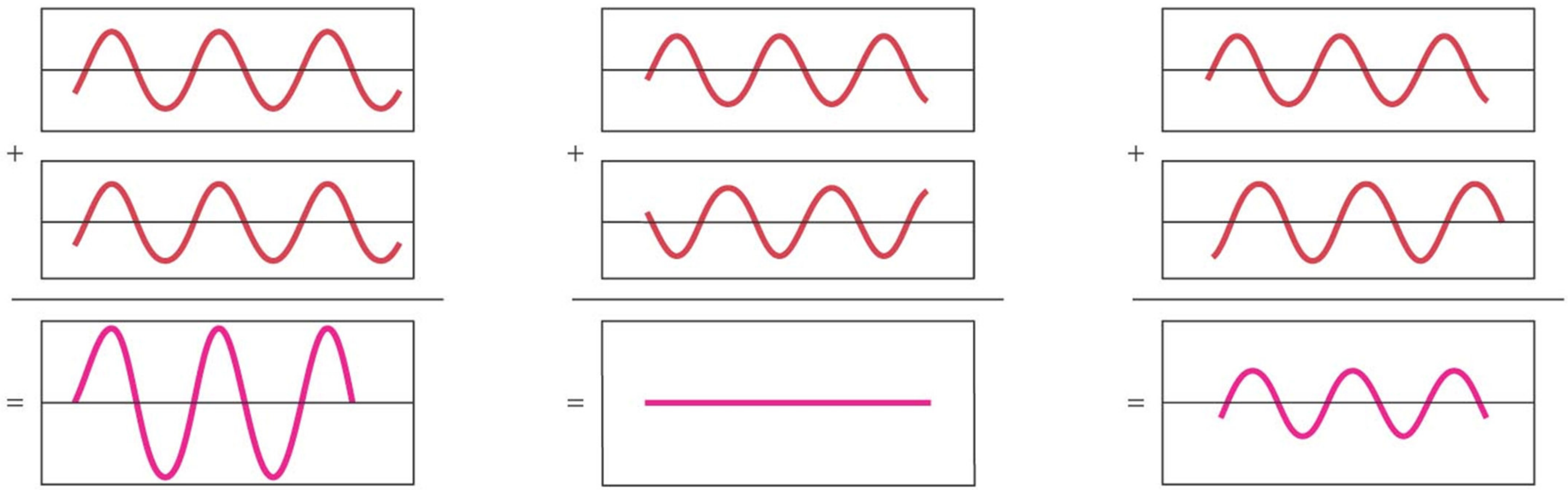


Waves in 2D and 3D



Superposition

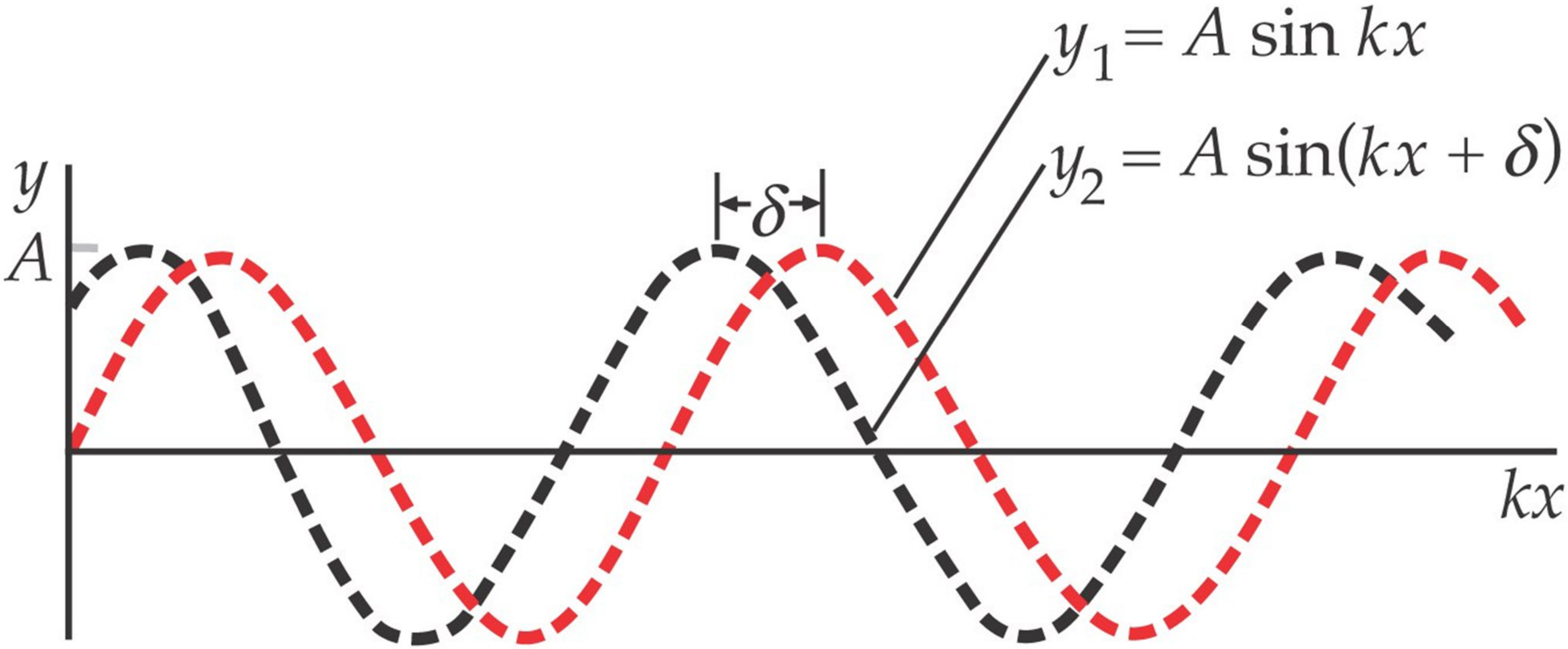

(a)
(b)
Pulses far apart, approaching
Time
Pulses overlap precisely (for an instant)
Pulses far apart, receding

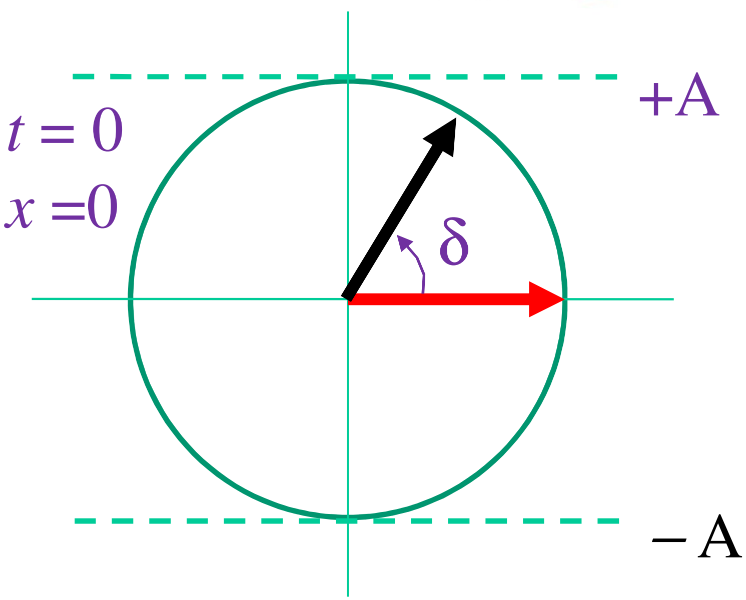


(a) (b) (c)

Constructive Interference

Destructive Interference

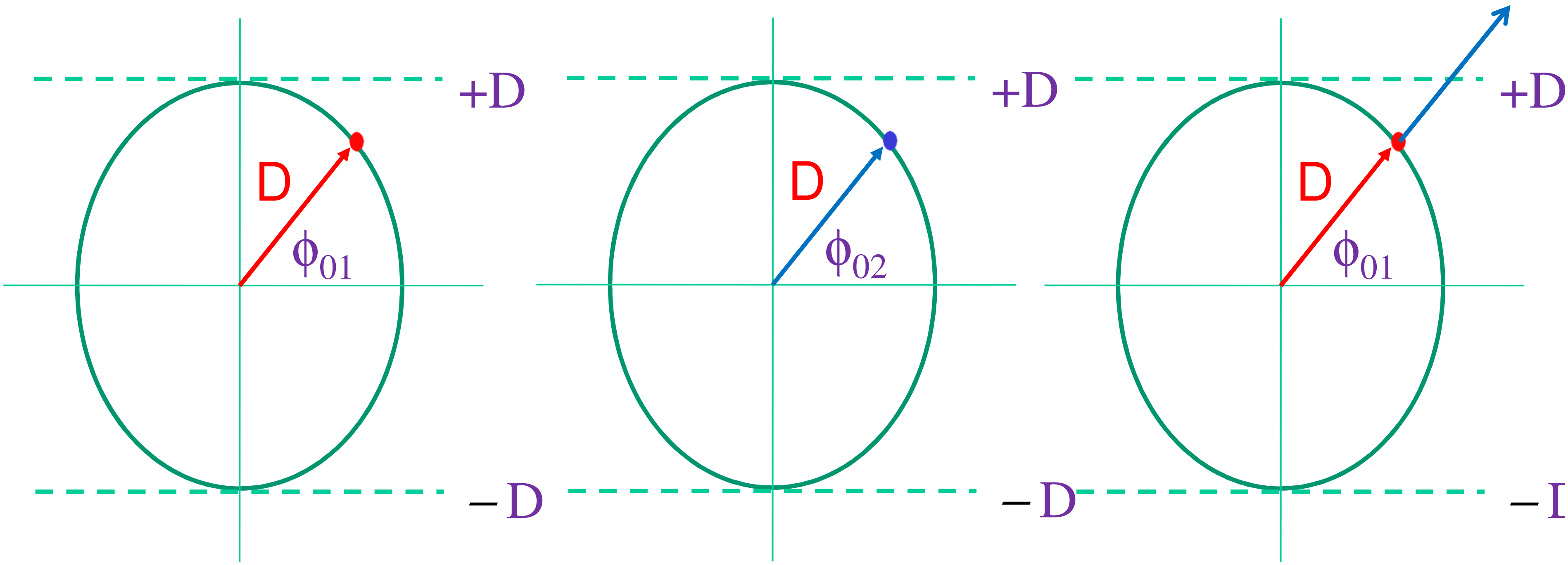




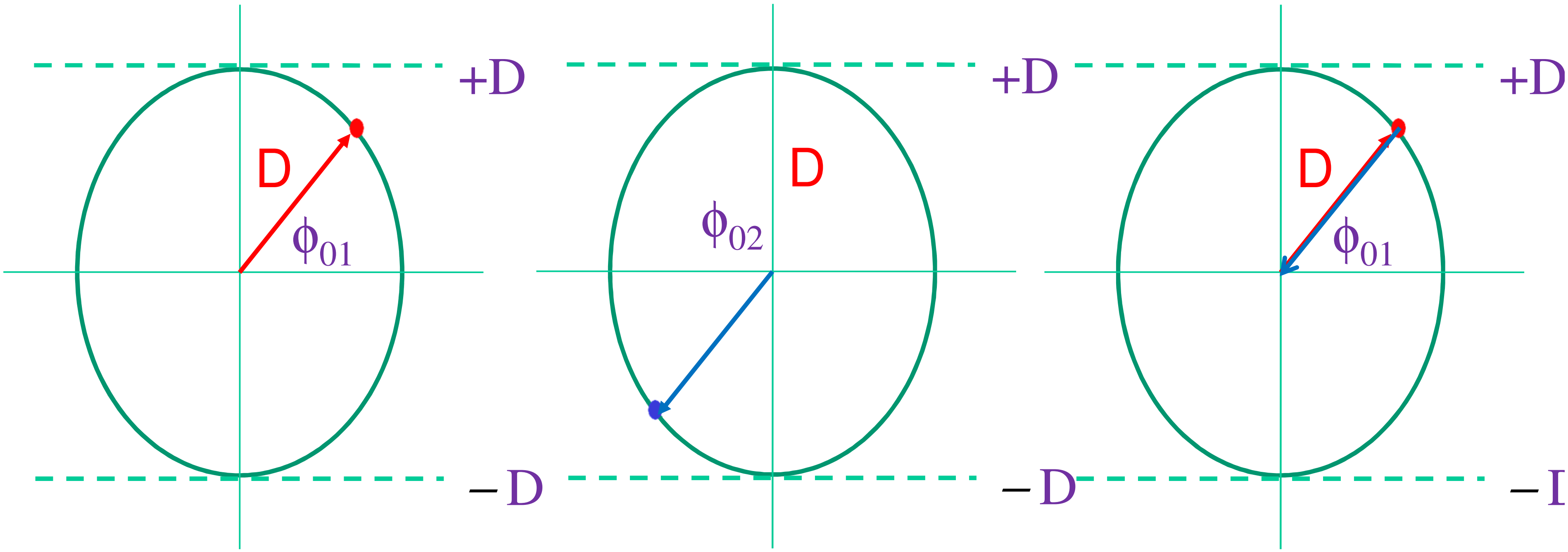
Black curve is said to lead red curve as it reaches maximum first or in ref circle vector has bigger phase constant.

Questions

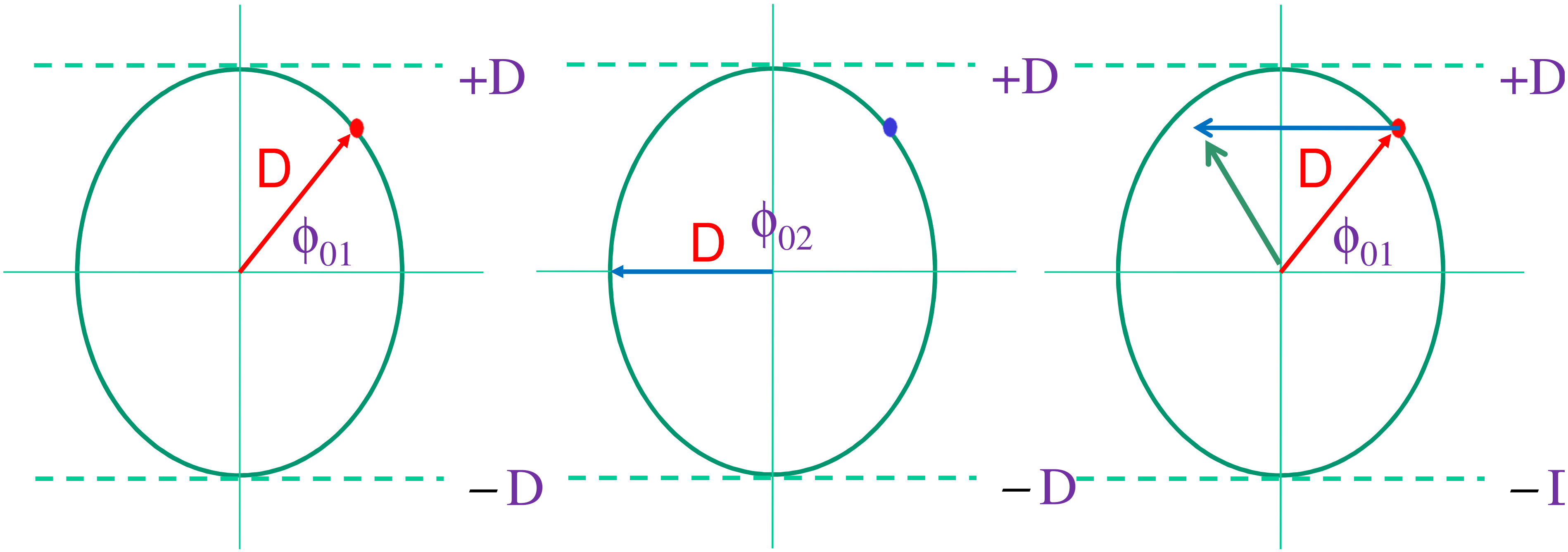
Constructive Interference



Destructive Interference



Inbetween Interference

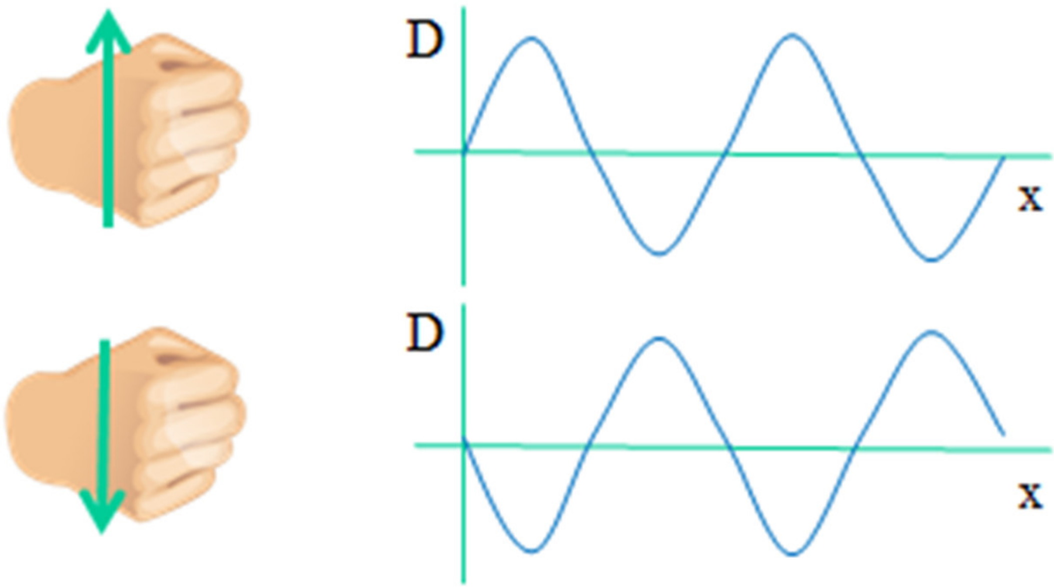


Conditions for Interference

$$\delta = \begin{cases} n2\pi & n = 0, 1, 2, \cdots \quad CI \\ m\pi & m = 1, 3, 5, \cdots \quad DI \end{cases}$$

How do we create a phase difference δ?

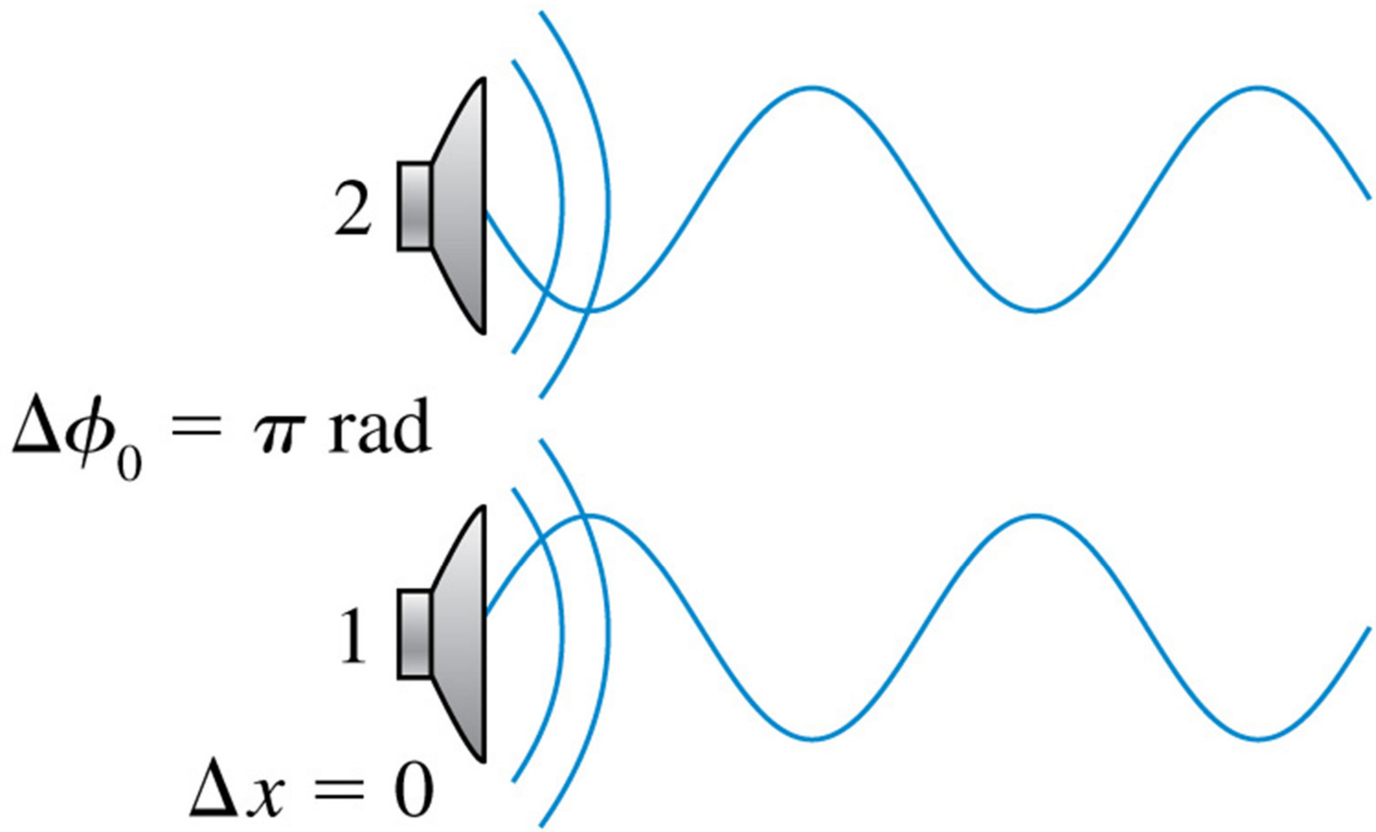
Interference by Differing Initial Phase



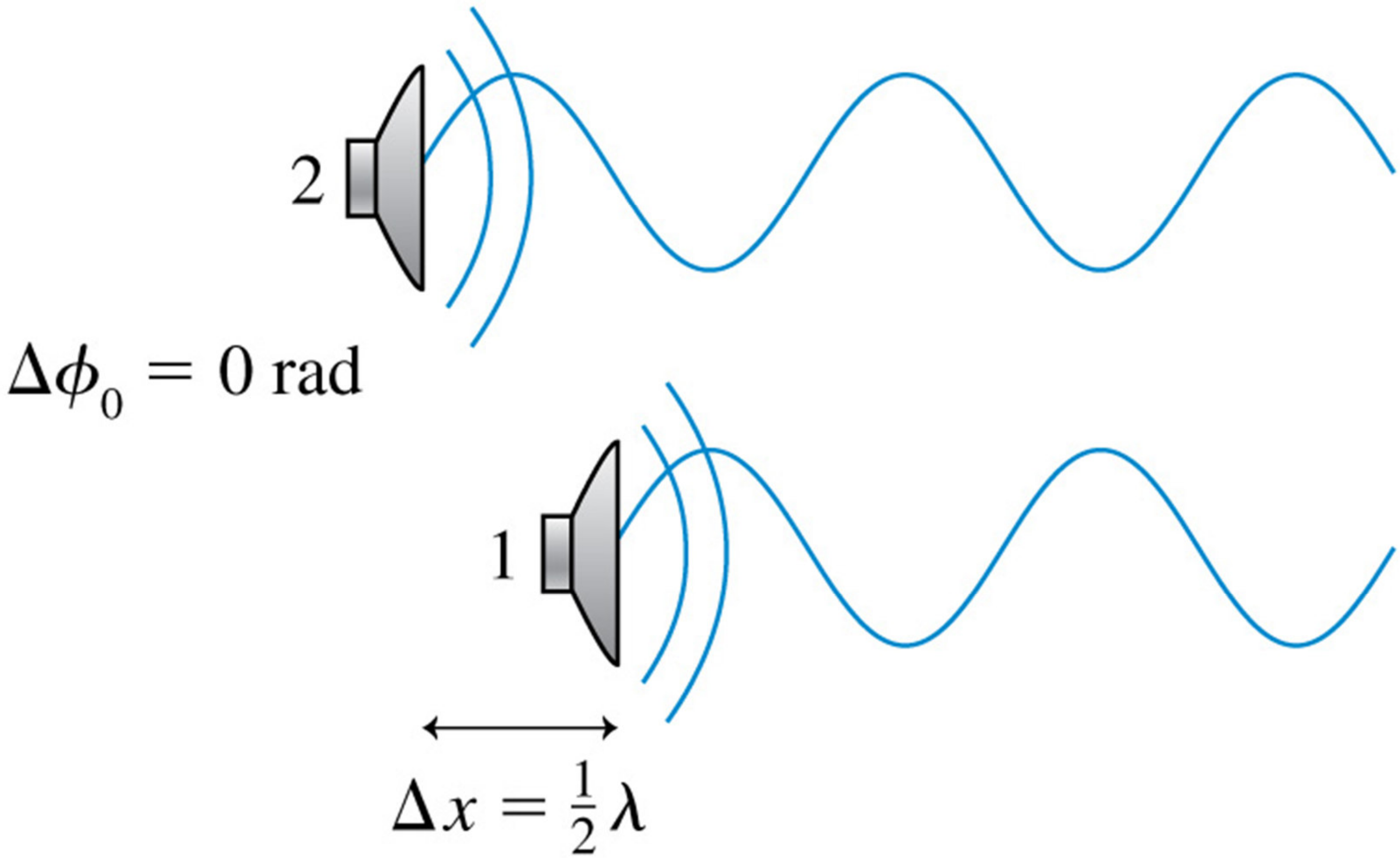
$$\delta = \phi_{bottom} - \phi_{top} = \pi - 0 = \pi$$

You can start off equilibrium to get and initial phase constant you want.

(a) The sources are out of phase.



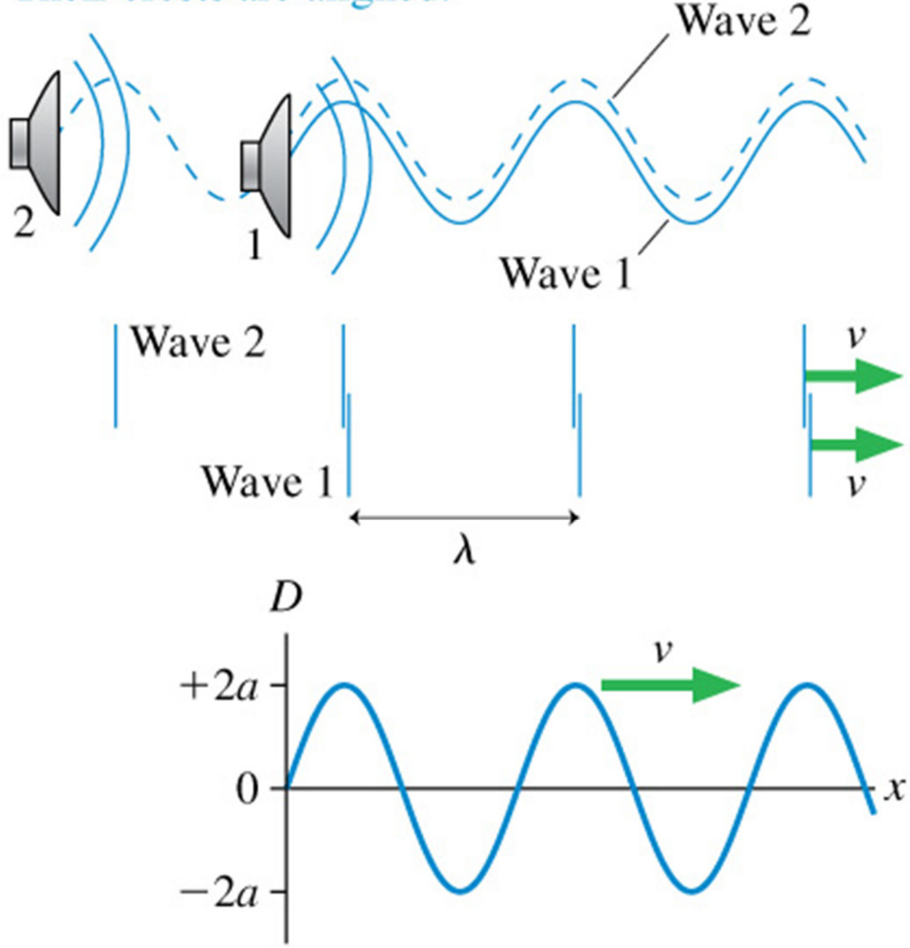
(b) Identical sources are separated by half a wavelength.



Path difference $\delta = 2\pi \, \Delta x / \lambda$

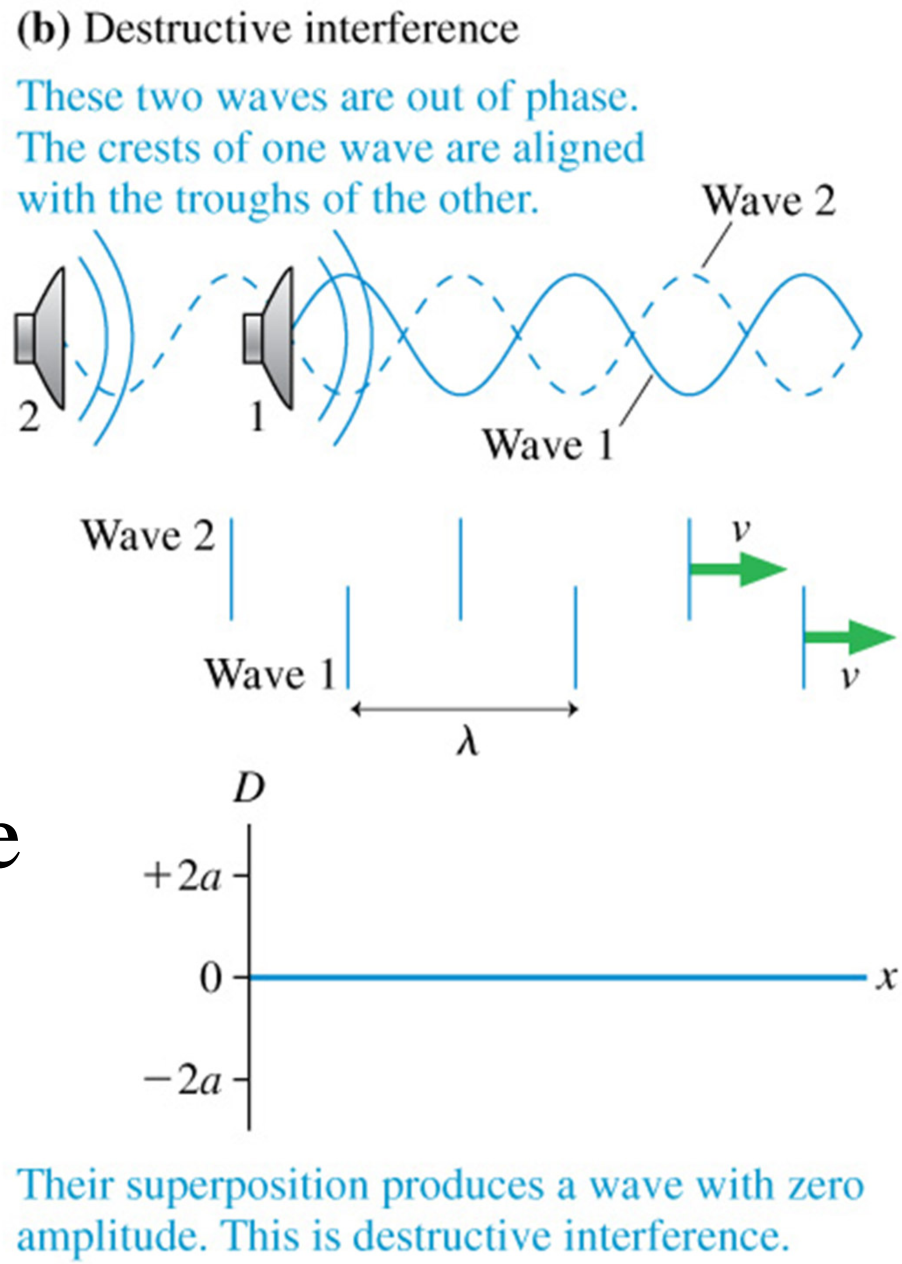
(a) Constructive interference

These two waves are in phase.
Their crests are aligned.

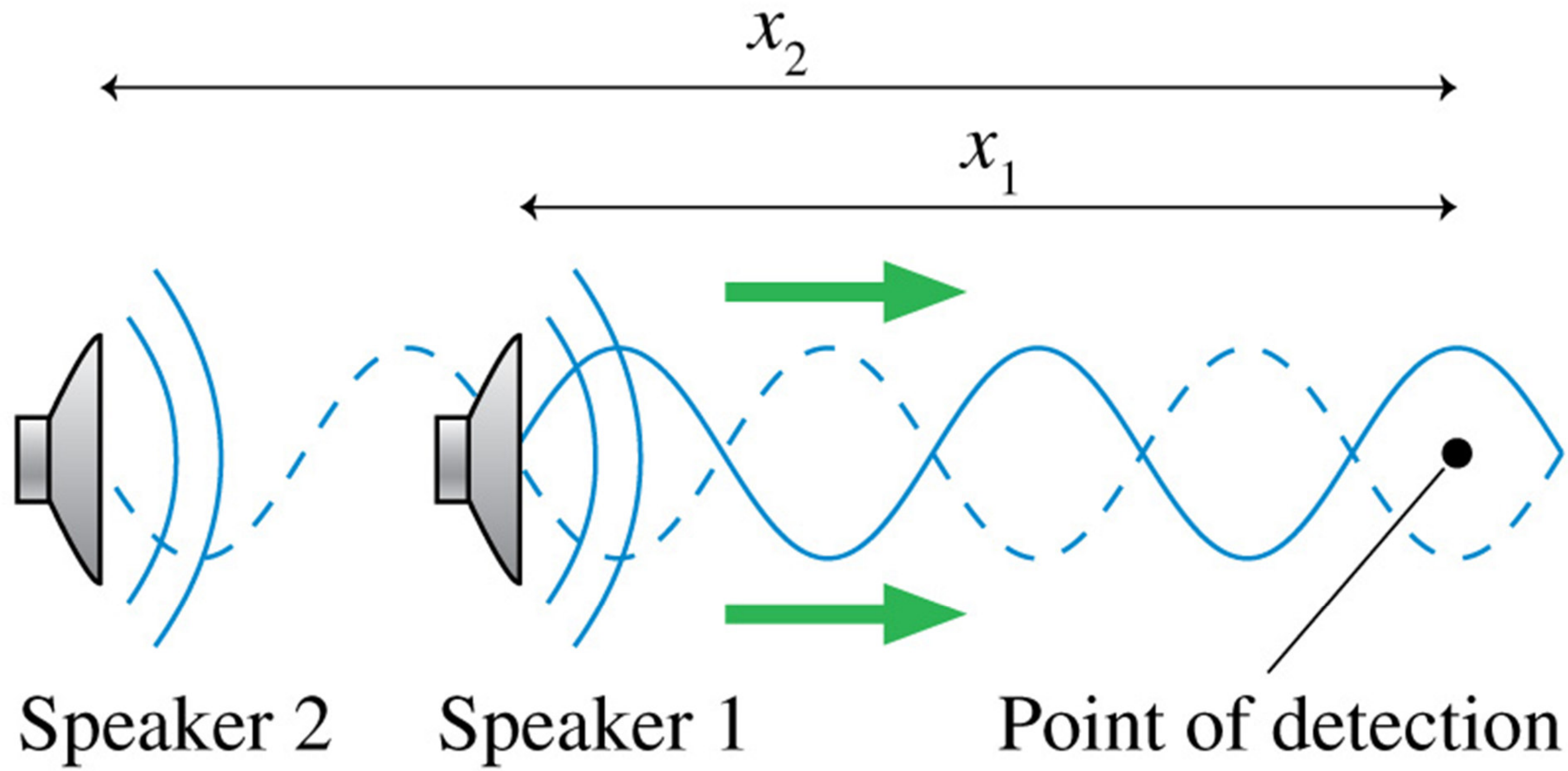


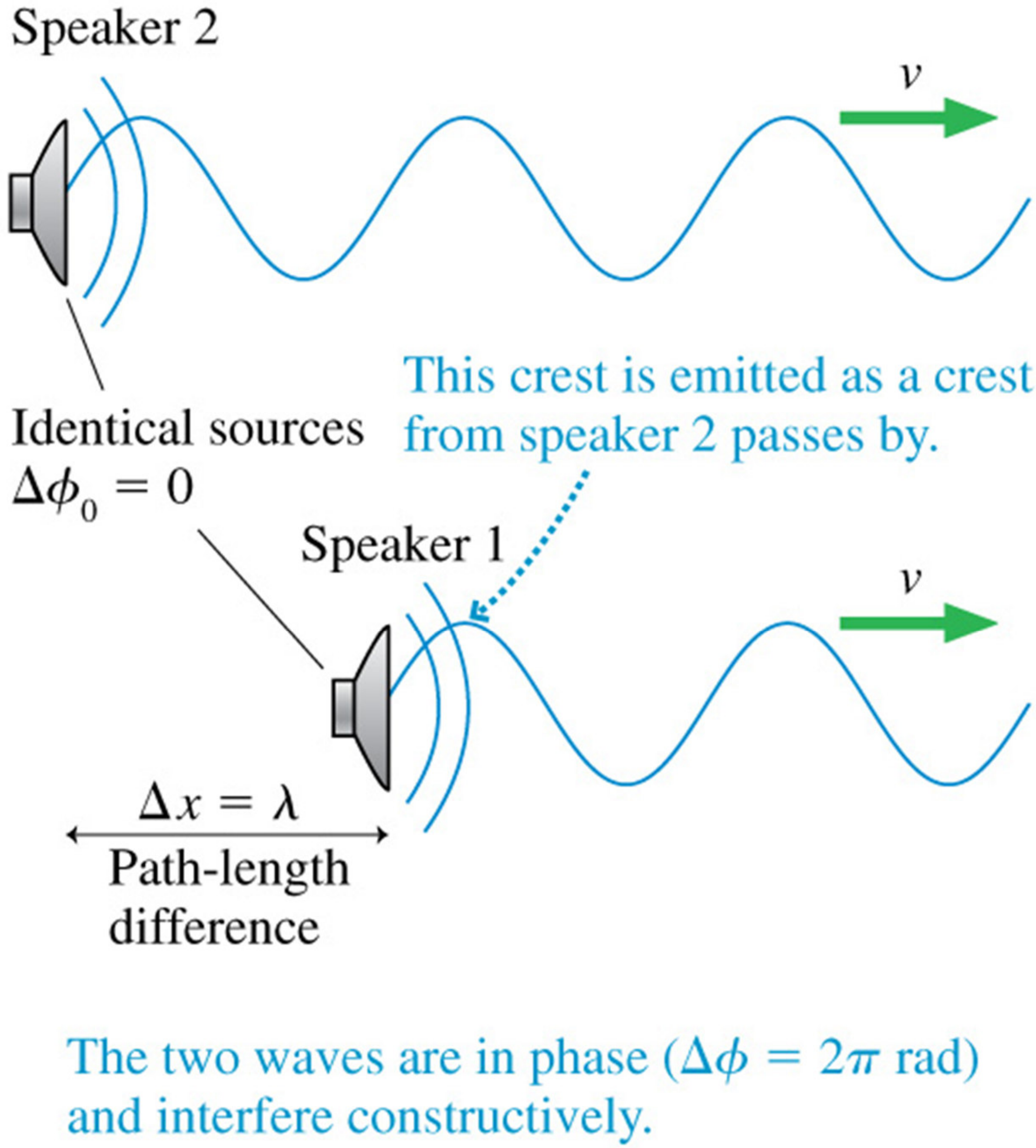
Their superposition produces a wave with amplitude $2a$. This is constructive interference.

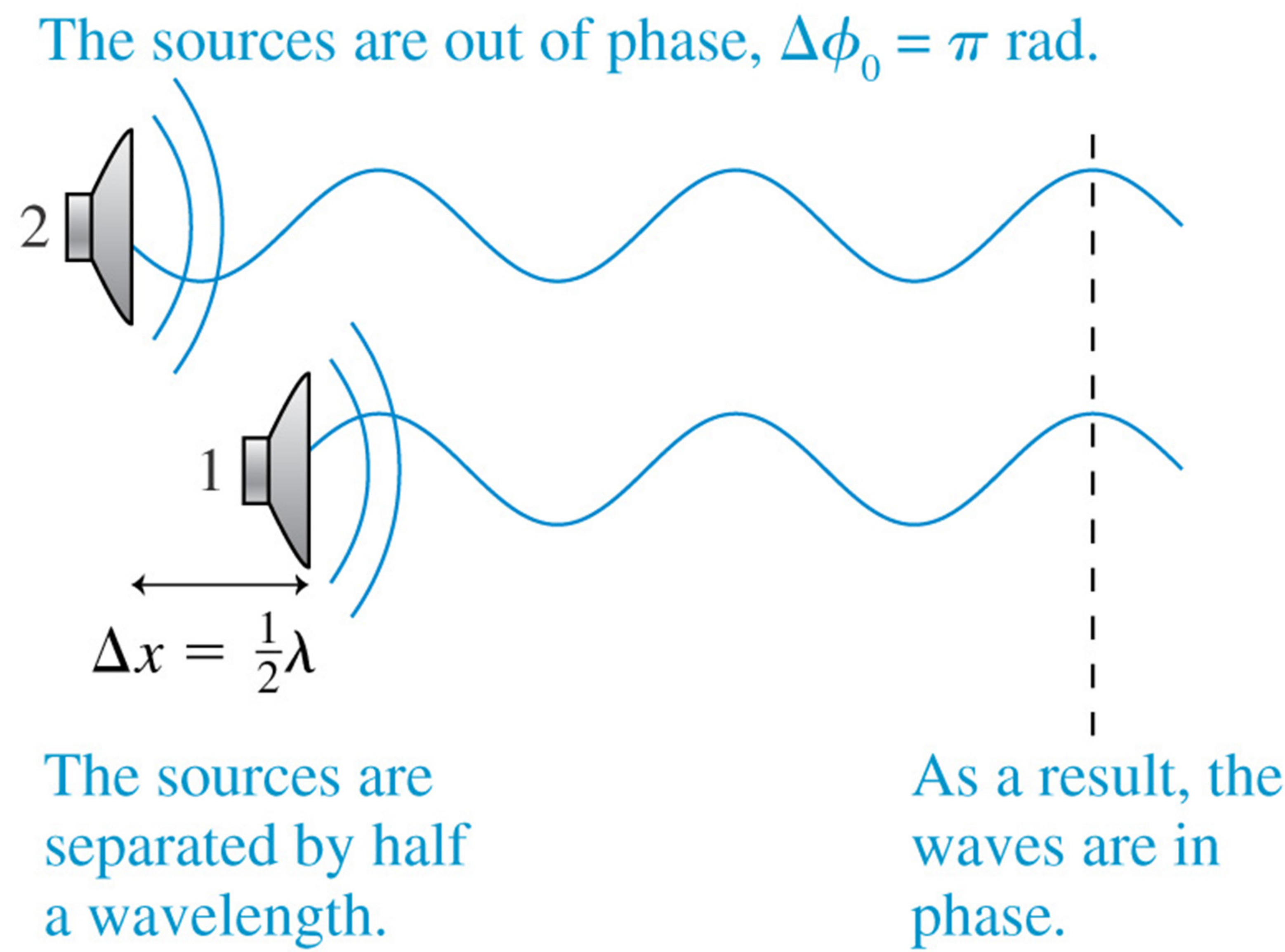
Can have both effects at same time



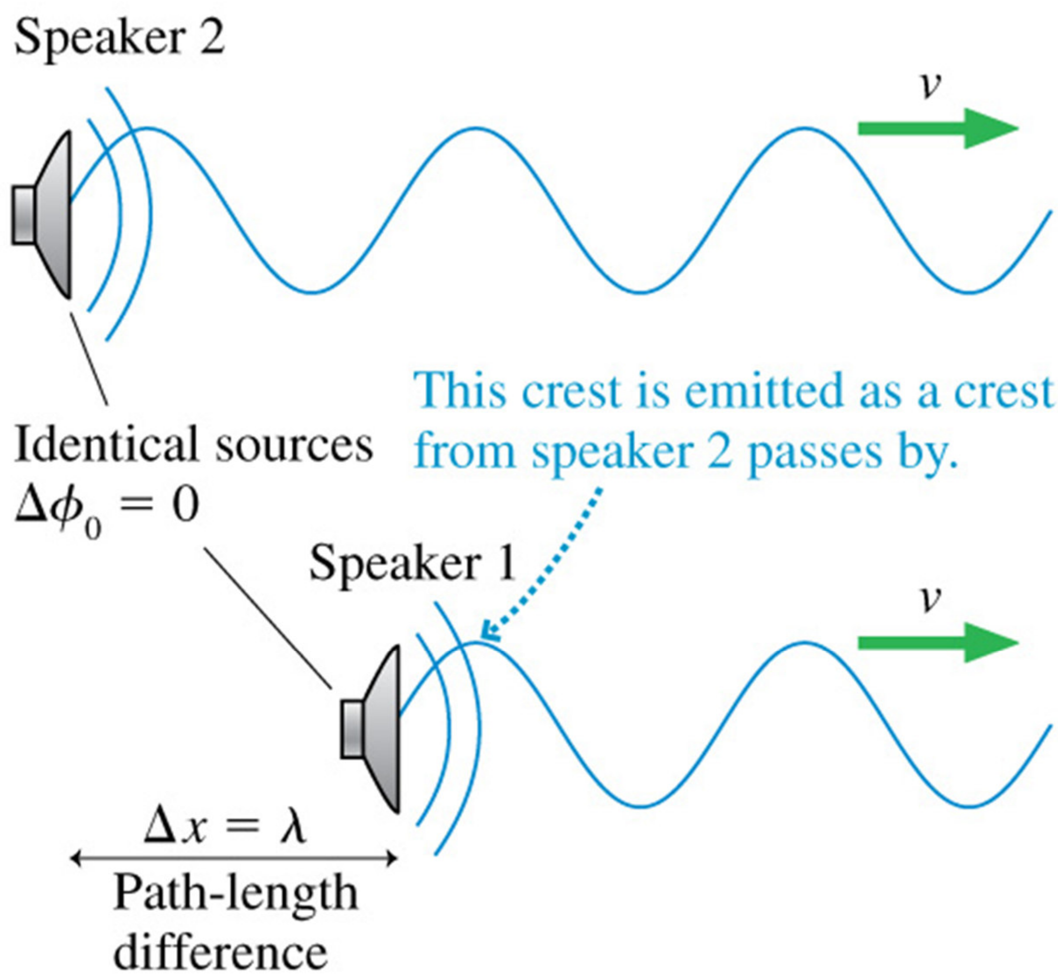
(b) Two overlapped sound waves




Speaker 2
v
This crest is emitted as a crest from speaker 2 passes by.
Identical sources $\Delta\phi_0 = 0$
Speaker 1
v
$\Delta x = \lambda$
Path-length difference
The two waves are in phase ($\Delta\phi = 2\pi$ rad) and interfere constructively.

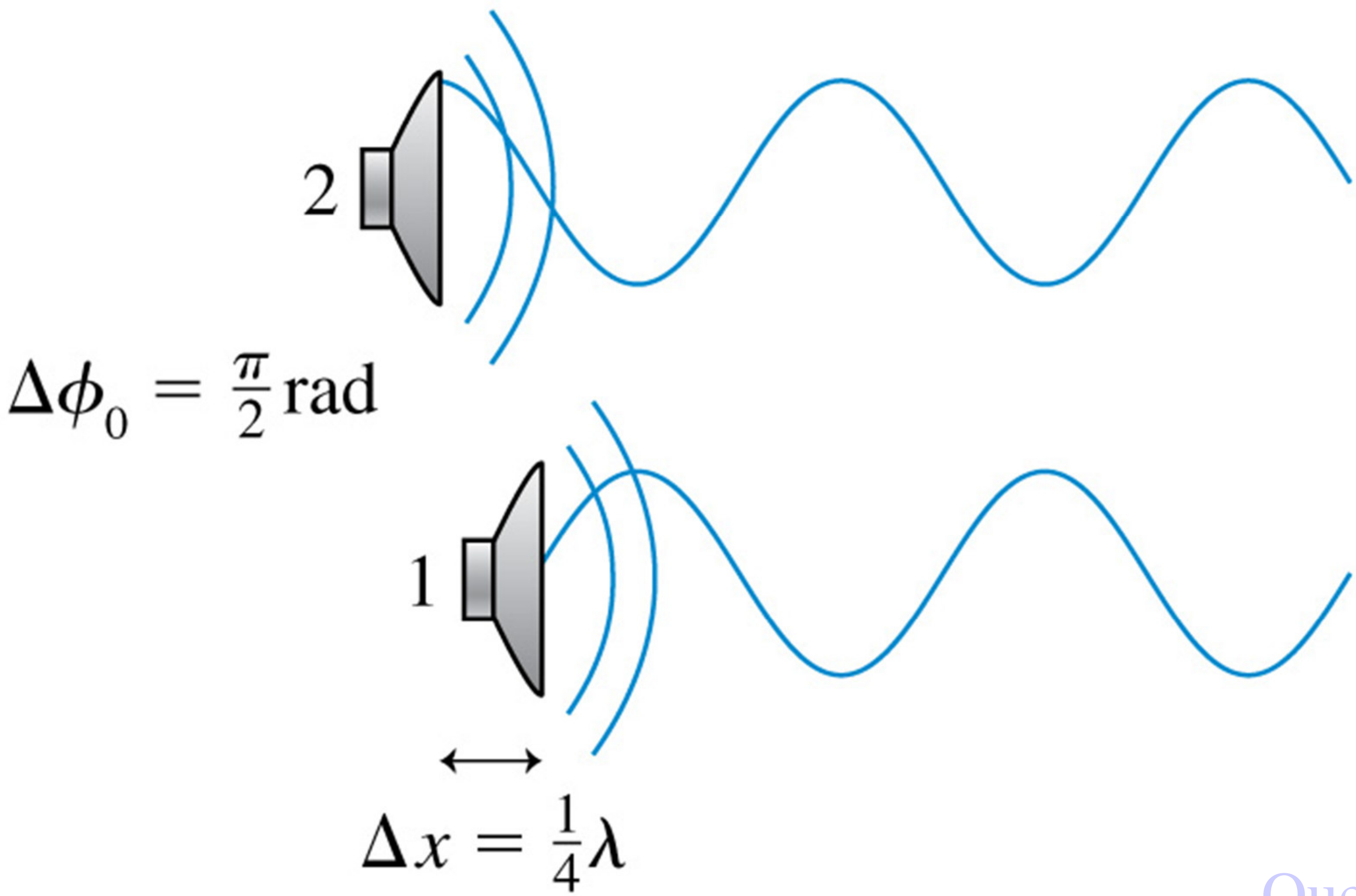


The sources are out of phase, $\Delta\phi_0 = \pi$ rad.
2
1
$\Delta x = \frac{1}{2}\lambda$
The sources are separated by half a wavelength.
As a result, the waves are in phase.



The two waves are in phase ($\Delta\phi = 2\pi$ rad) and interfere constructively.

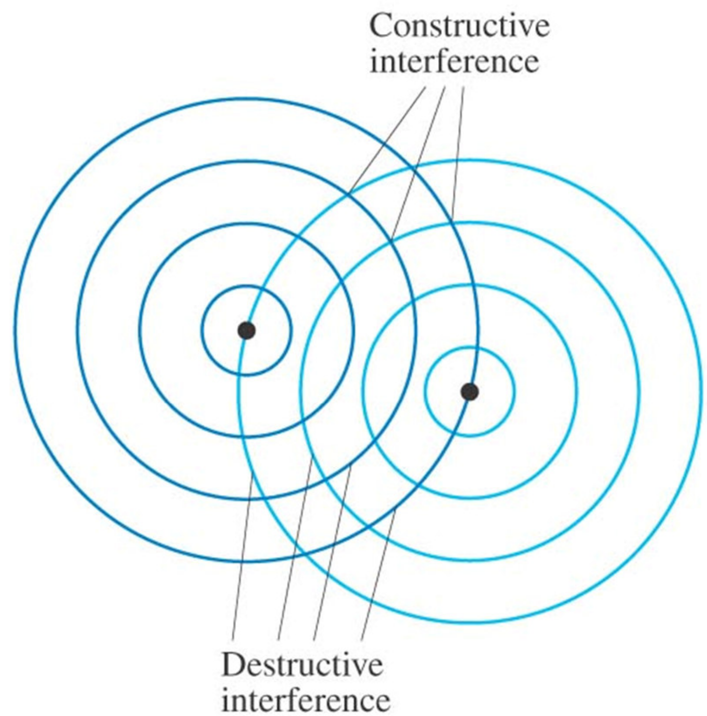
(c) The sources are both separated and partially out of phase.



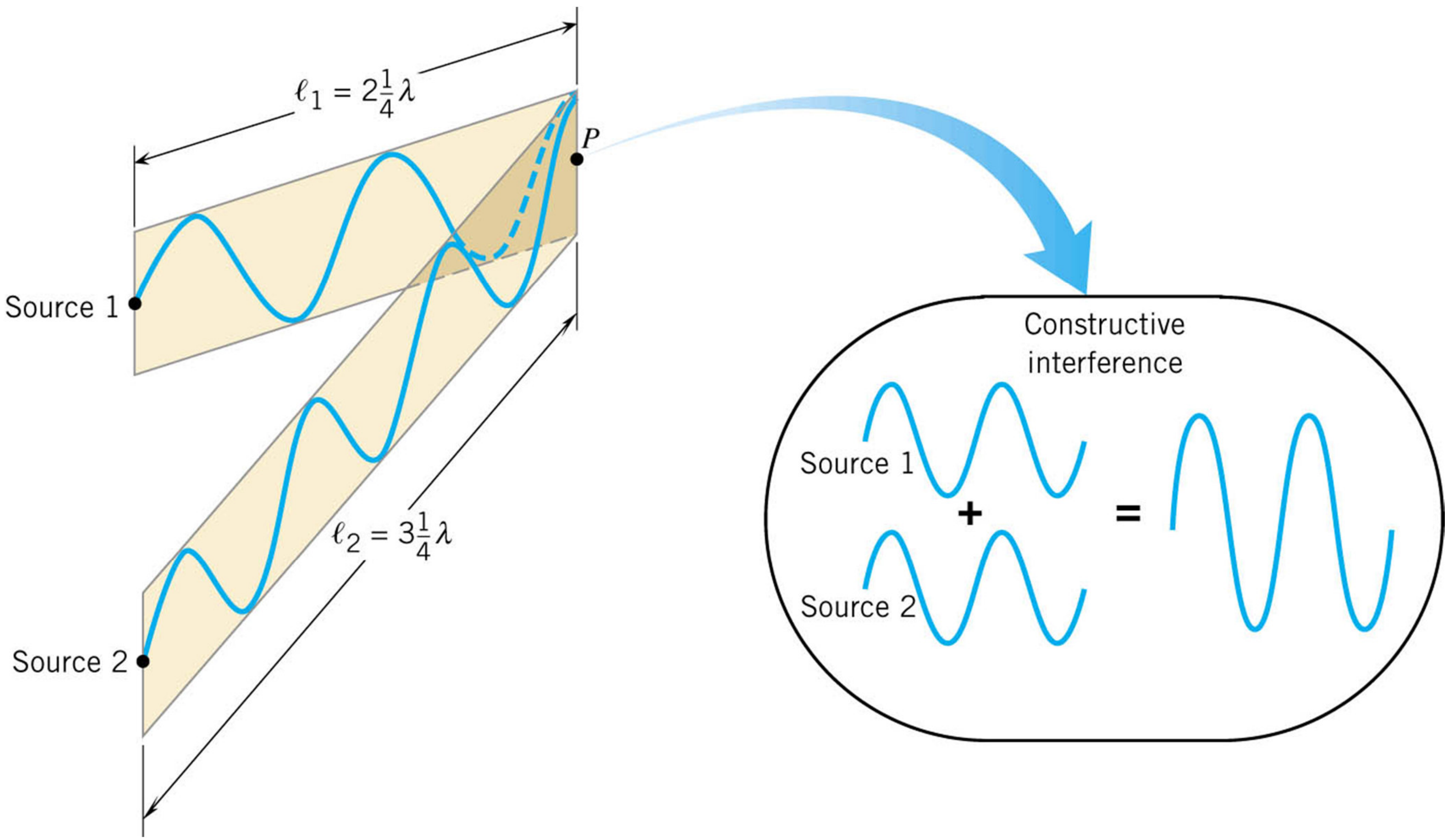
Questions

Superposition in 2D

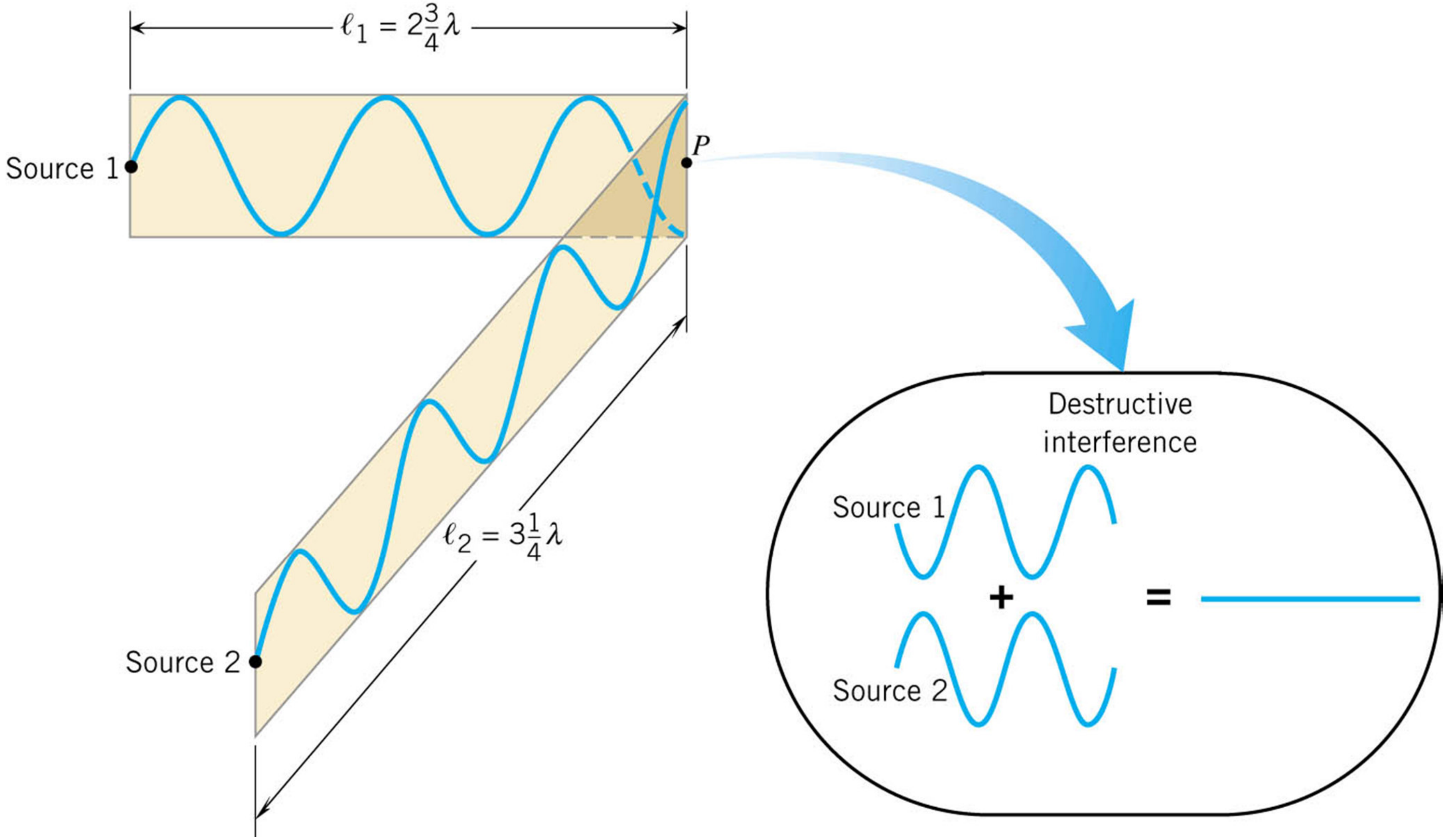
(a)



(b)



$\ell_1 = 2\frac{1}{4}\lambda$
P
Source 1
Source 2
$\ell_2 = 3\frac{1}{4}\lambda$
Constructive interference
Source 1
+
Source 2
=

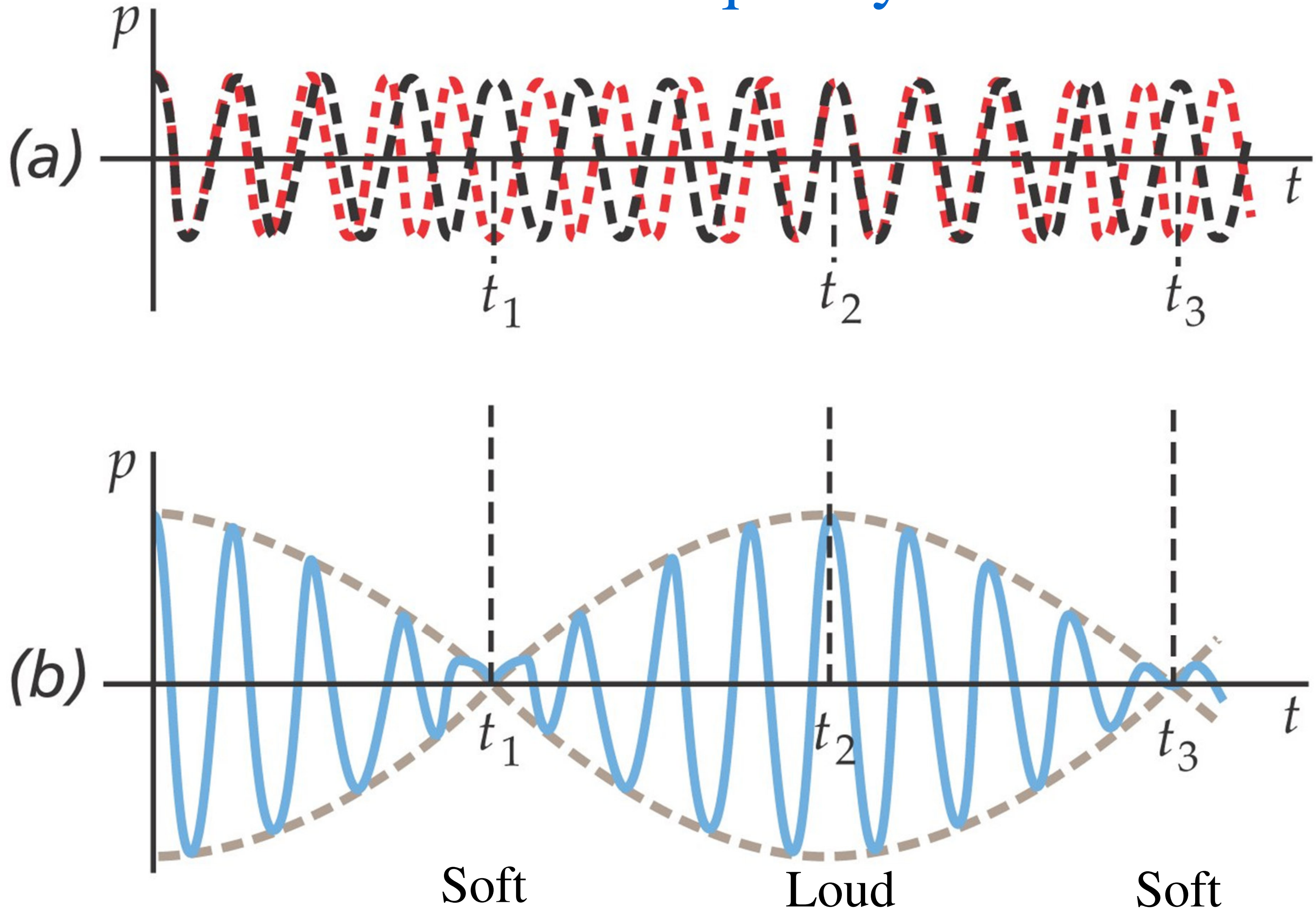


$\ell_1 = 2\frac{3}{4}\lambda$
Source 1
P
$\ell_2 = 3\frac{1}{4}\lambda$
Source 2
Destructive interference
Source 1
+
=
Source 2

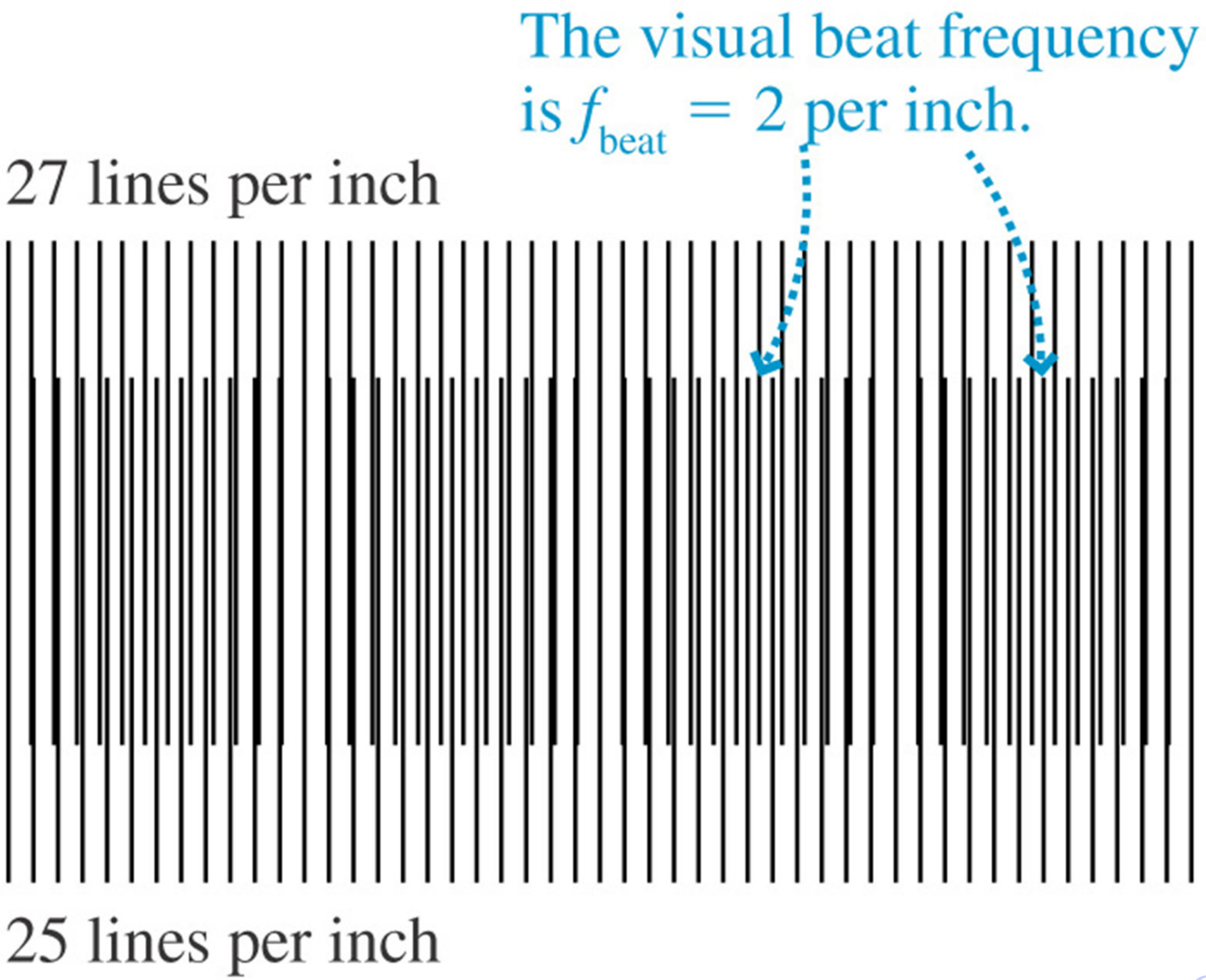
Questions

Beats

Beat Frequency



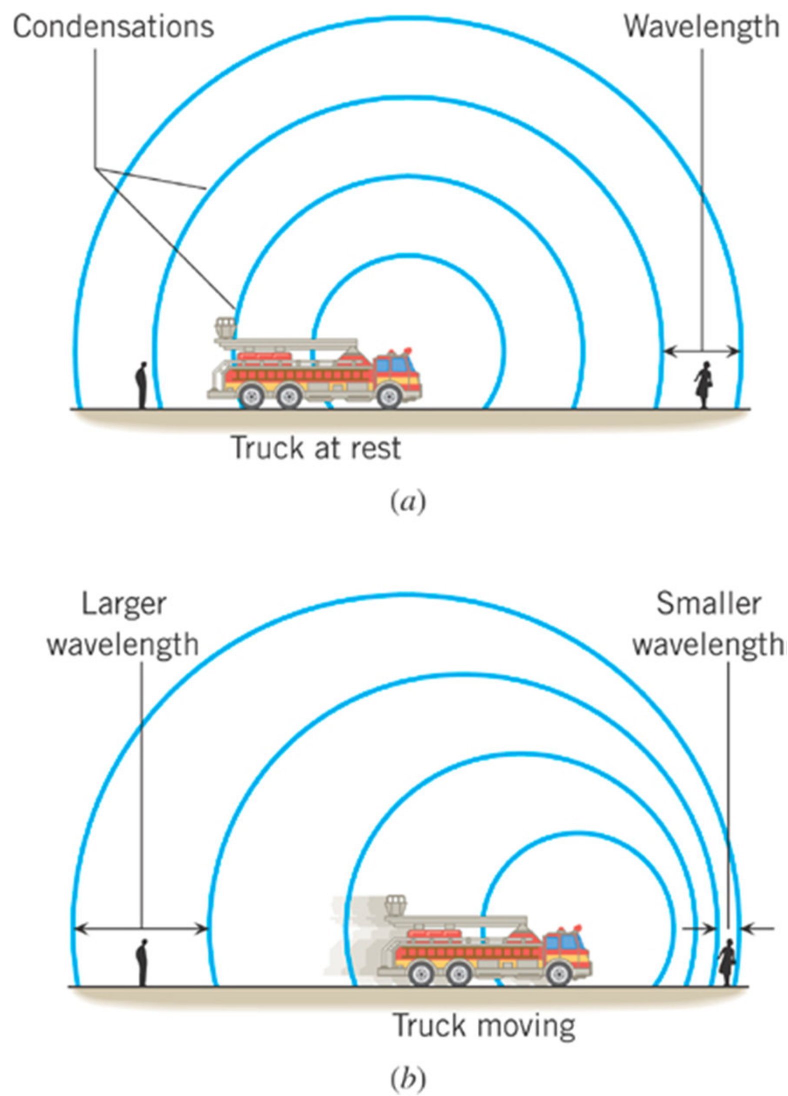
$$f_{beat} = |f_1 - f_2|$$



The visual beat frequency is $f_{beat} = 2$ per inch.
27 lines per inch
25 lines per inch

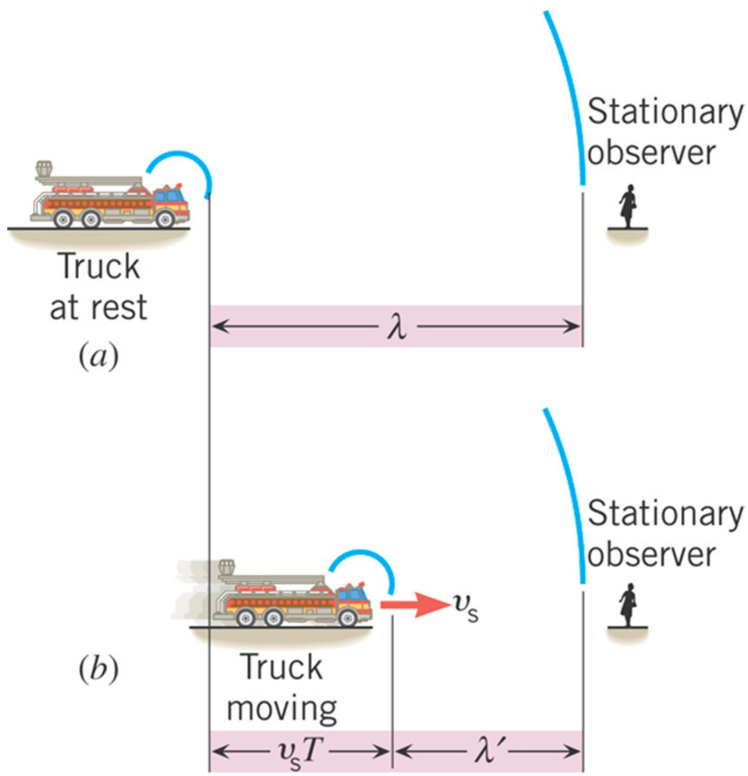
Questions

16.9 The Doppler Effect



The ***Doppler effect*** is the change in frequency or pitch of the sound detected by an observer because the sound source and the observer have different velocities with respect to the medium of sound propagation.

MOVING SOURCE



$$\lambda' = \lambda - v_s T$$

$$f_o = \frac{v}{\lambda'} = \frac{v}{\lambda - v_s T} = \frac{v}{v/f_s - v_s/f_s}$$

$$f_o = f_s\left(\frac{1}{1 - v_s/v}\right)$$

16.9 The Doppler Effect

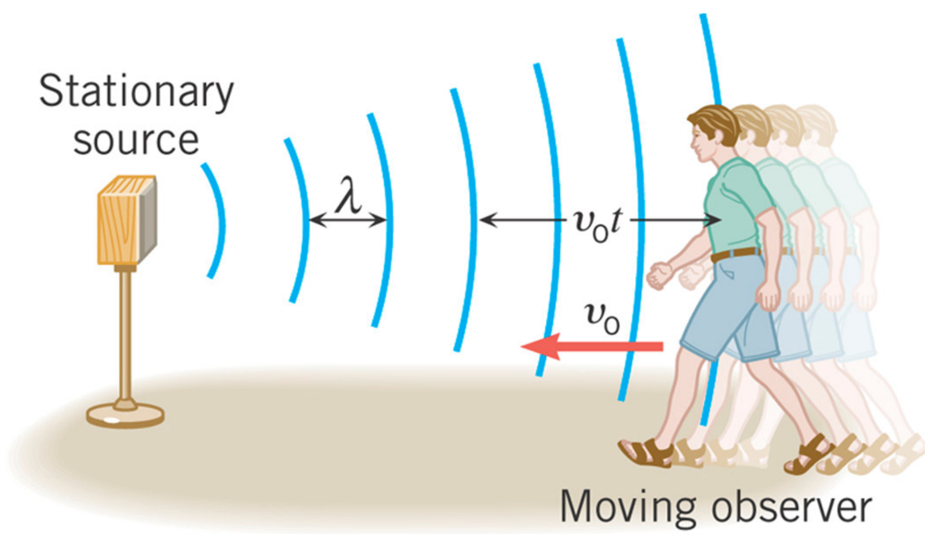
source moving toward a stationary observer

$$f_o = f_s \left(\frac{1}{1 - v_s / v} \right)$$

source moving away from a stationary observer

$$f_o = f_s \left(\frac{1}{1 + v_s / v} \right)$$

MOVING OBSERVER



$$f_o = f_s + \frac{v_o}{\lambda} = f_s\left(1 + \frac{v_o}{f_s\lambda}\right)$$

$$= f_s\left(1 + \frac{v_o}{v}\right)$$

16.9 The Doppler Effect

Observer moving towards stationary source

$$f_o = f_s\left(1 + \frac{v_o}{v}\right)$$

Observer moving away from stationary source

$$f_o = f_s\left(1 - \frac{v_o}{v}\right)$$

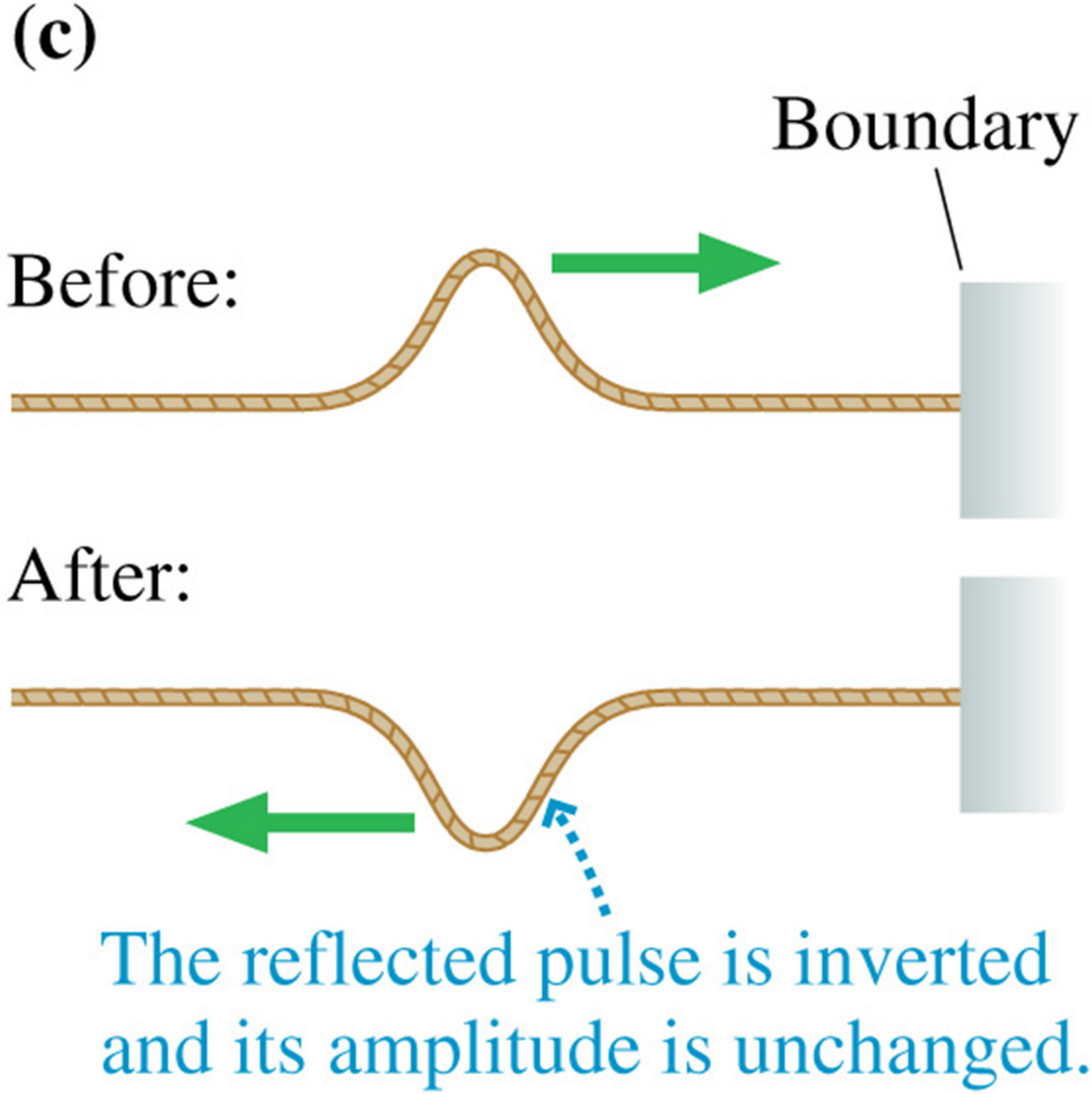
GENERAL CASE

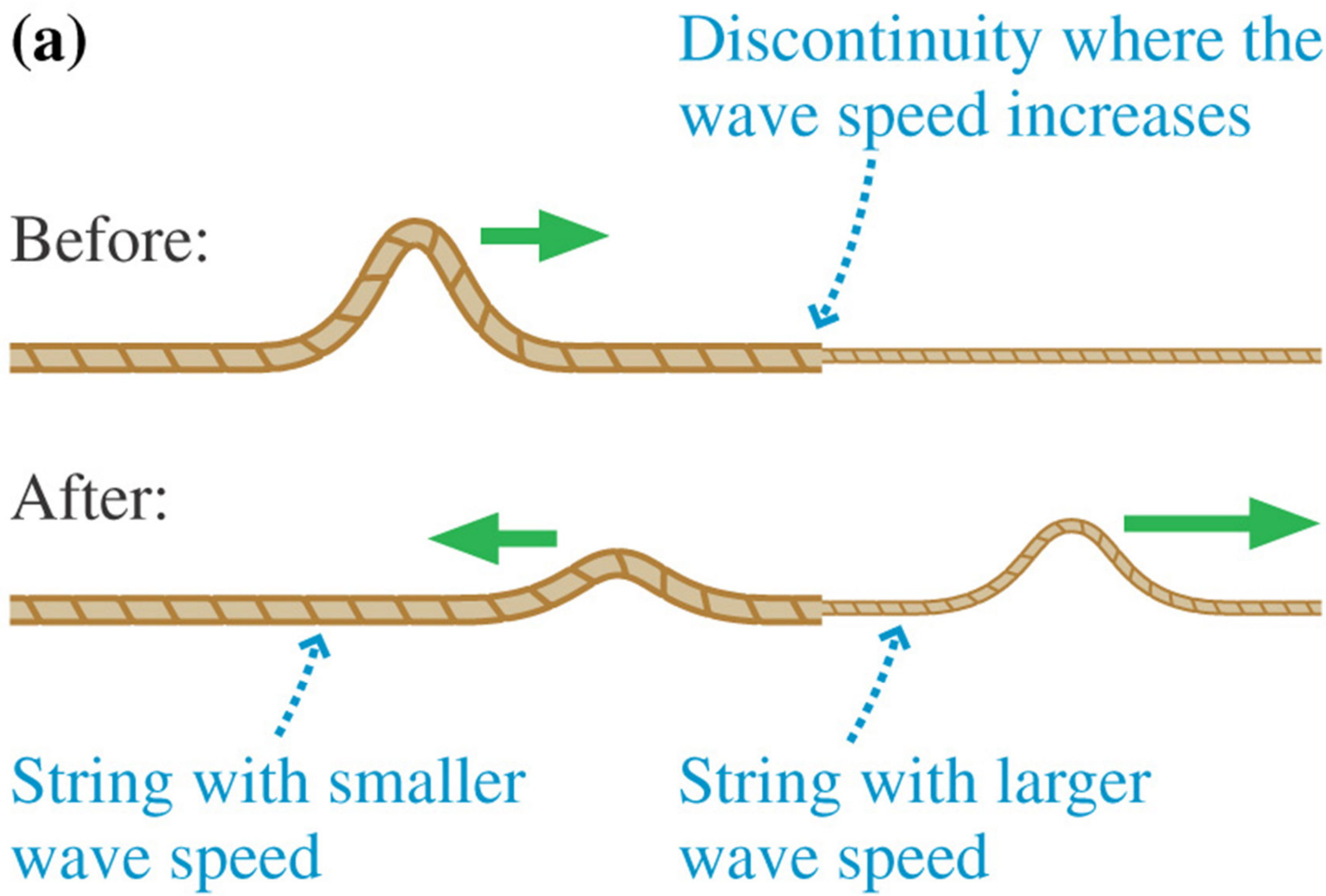
Numerator: plus sign applies when observer moves towards the source

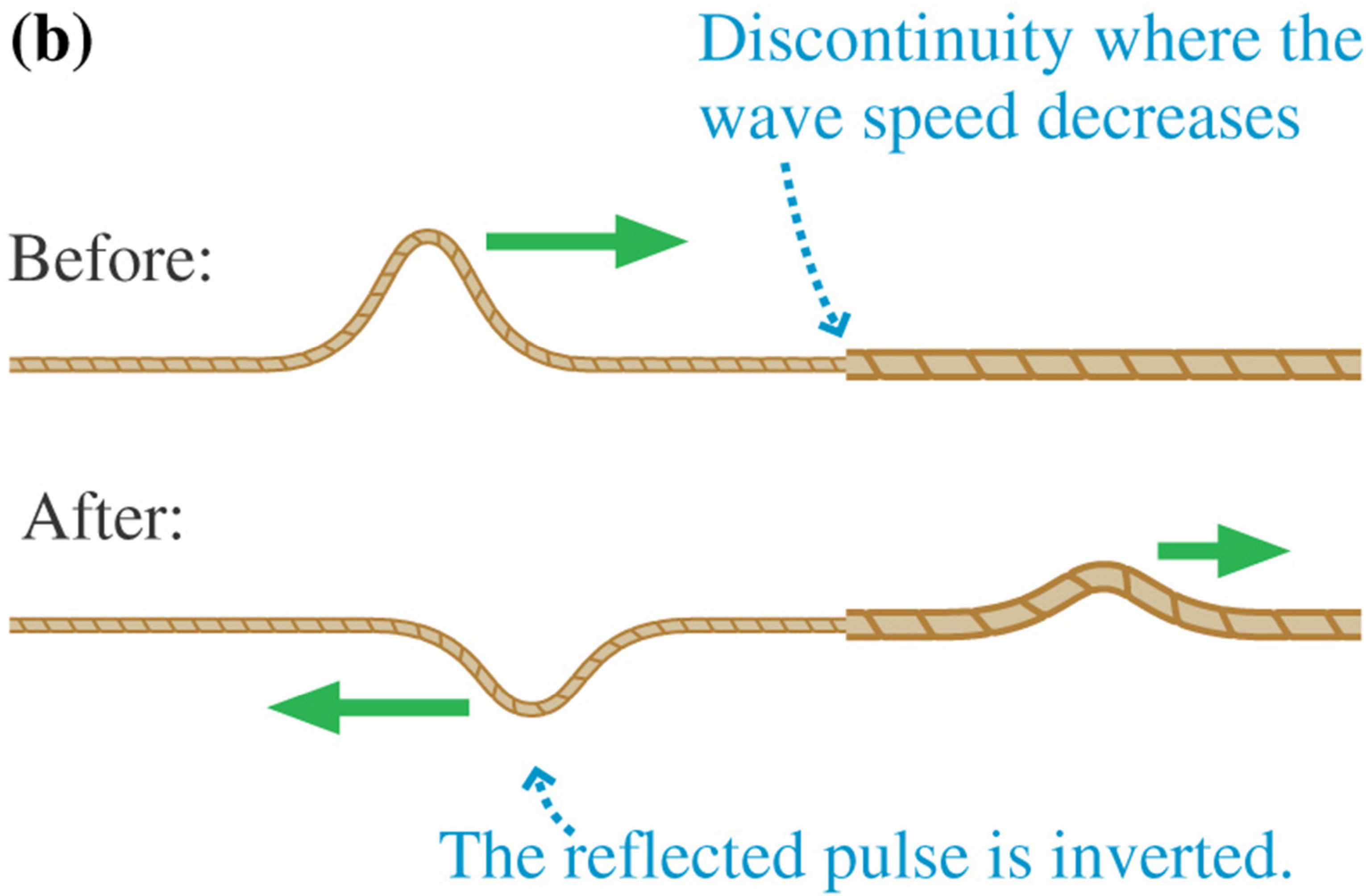
$$f_o = f_s \left(\frac{1 \pm \frac{v_o}{v}}{1 \mp \frac{v_s}{v}} \right)$$

Denominator: minus sign applies when source moves towards the observer

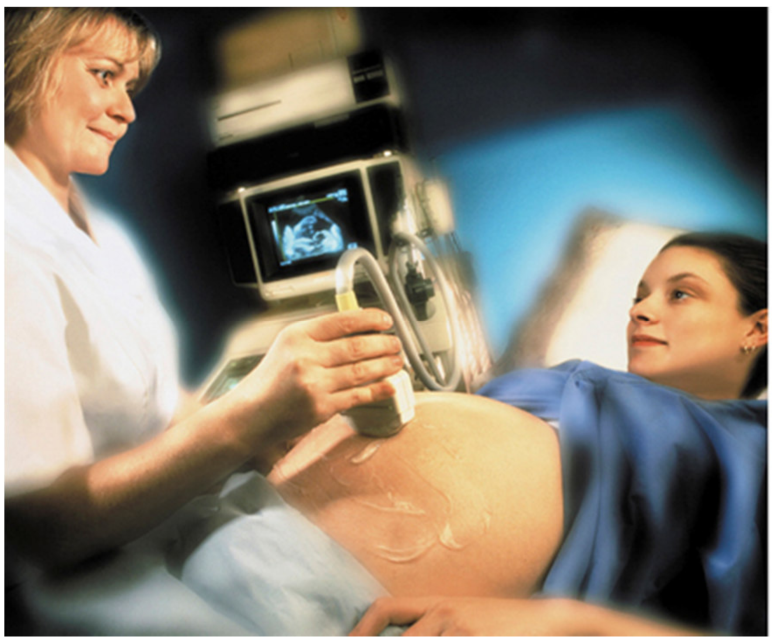
Know when observed frequency is high or low


(c)
Boundary
Before:
After:
The reflected pulse is inverted
and its amplitude is unchanged.

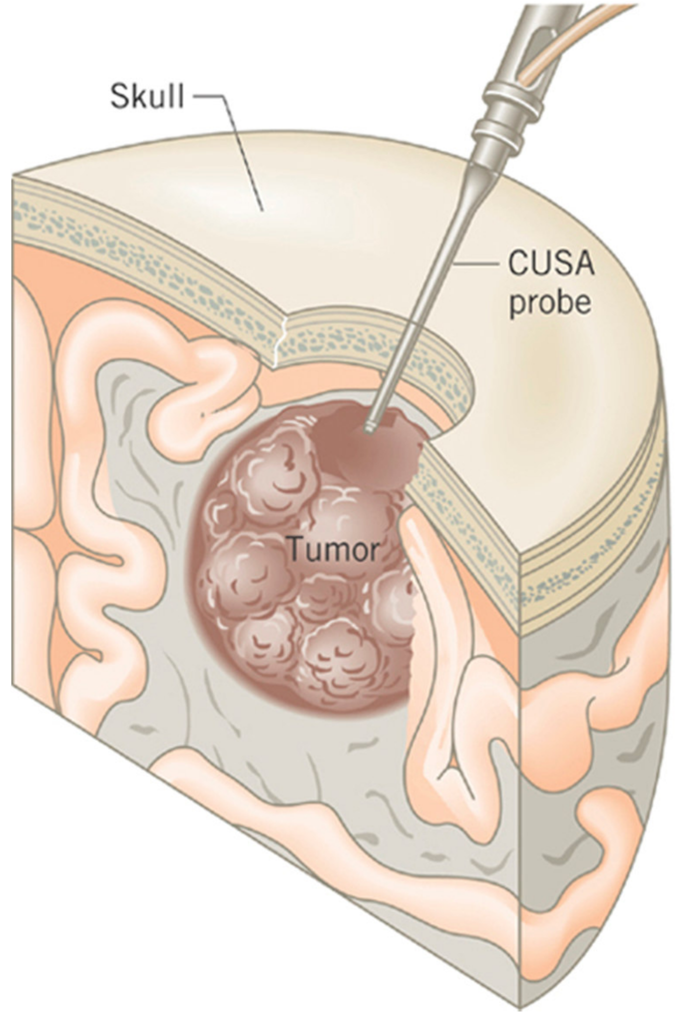

(a)
Discontinuity where the wave speed increases
Before:
After:
String with smaller wave speed
String with larger wave speed


(b)
Discontinuity where the wave speed decreases
Before:
After:
The reflected pulse is inverted.

By scanning ultrasonic waves across the body and detecting the echoes from various locations, it is possible to obtain an image.



Ultrasonic sound waves cause the tip of the probe to vibrate at 23 kHz and shatter sections of the tumor that it touches.



When the sound is reflected from the red blood cells, its frequency is changed in a kind of Doppler effect because the cells are moving.