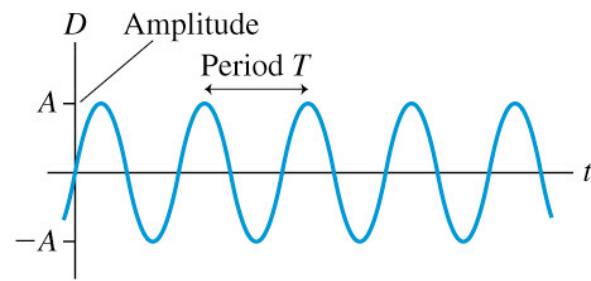


Lecture 8

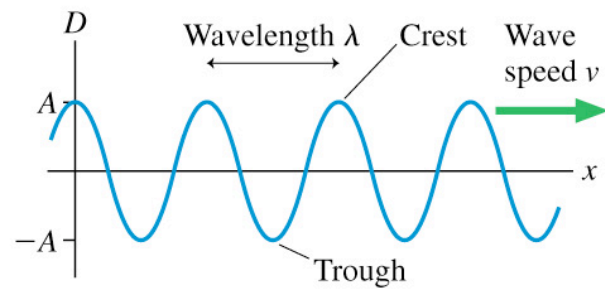
- Sinusoidal waves
- Wave speed on a string
- 2D/3D waves
- Sound and Light

Sinusoidal waves (graphical)

(a) A history graph at one point in space



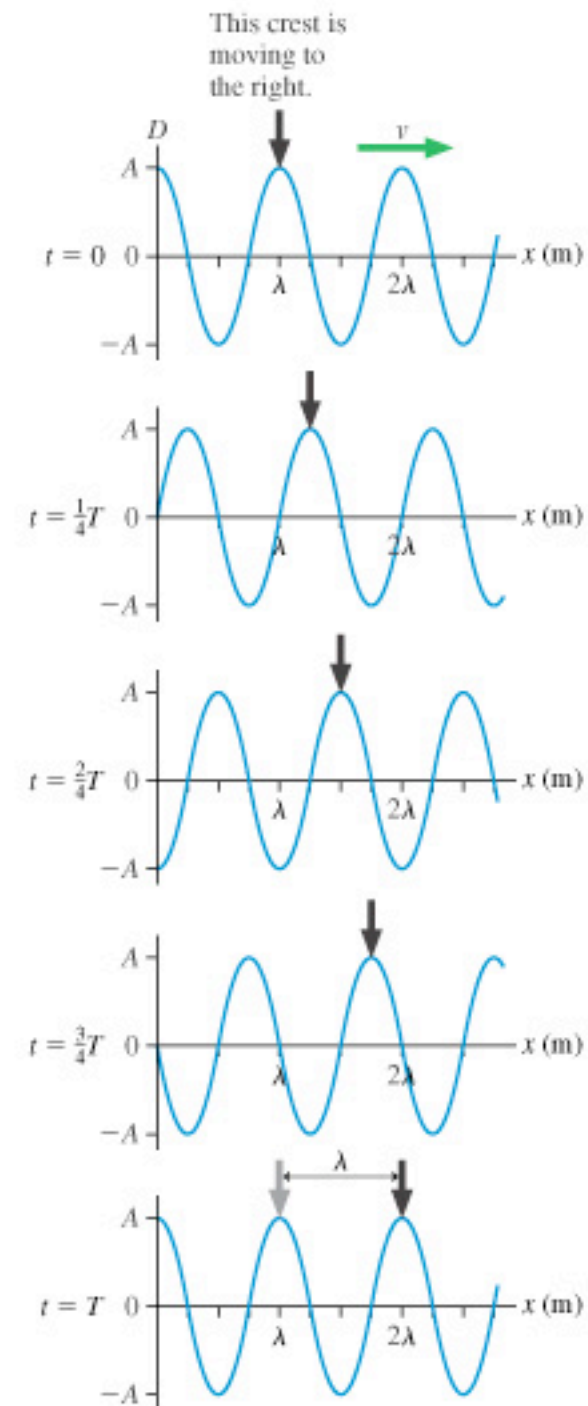
(b) A snapshot graph at one instant of time



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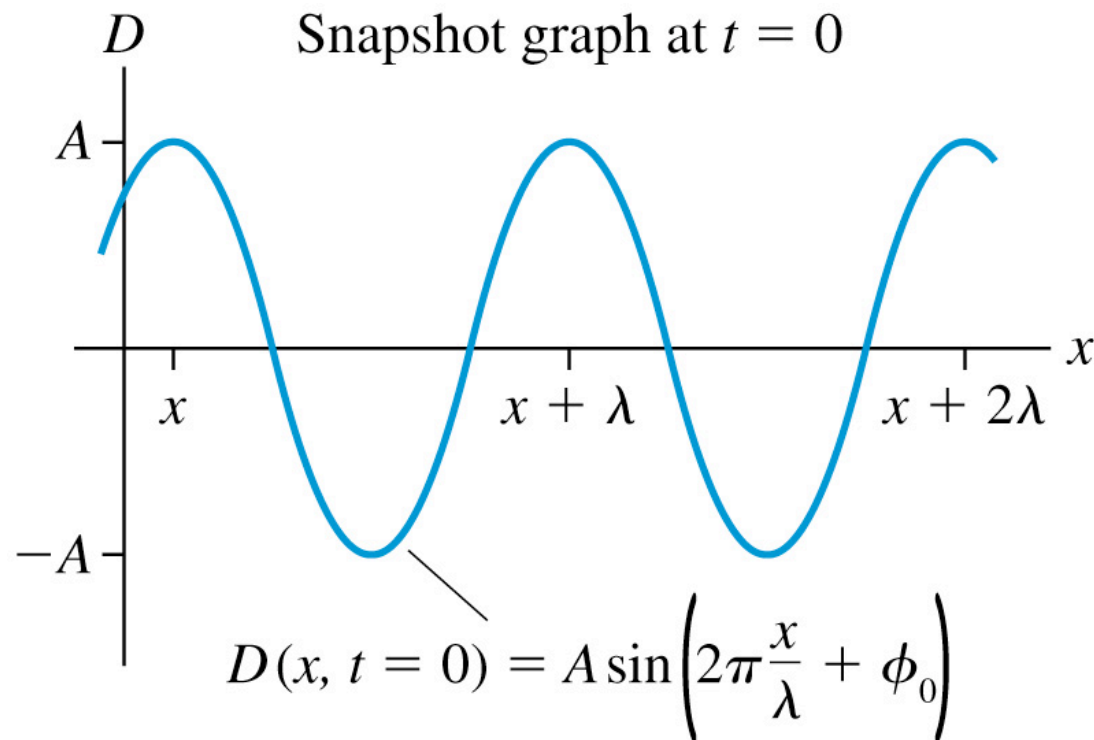
- generated by source in SHM
- snapshot and history graphs sinusoidal/periodic in space, time
- Wavelength (λ): spatial analog of T , distance disturbance repeats
- In time T : (one oscillation for point) wave (crest) moves λ

$$v = \frac{\text{distance}}{\text{time}} = \frac{\lambda}{T} = \lambda f$$



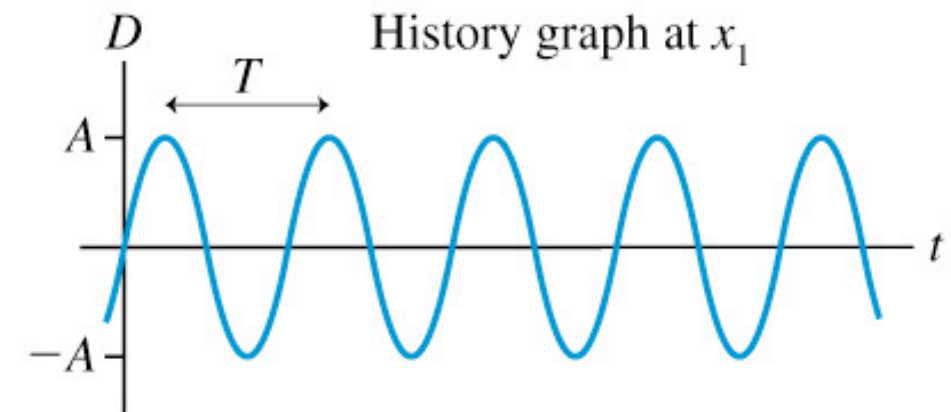
During a time interval of exactly one period, the crest has moved forward exactly one wavelength.

Sinusoidal waves:mathematical

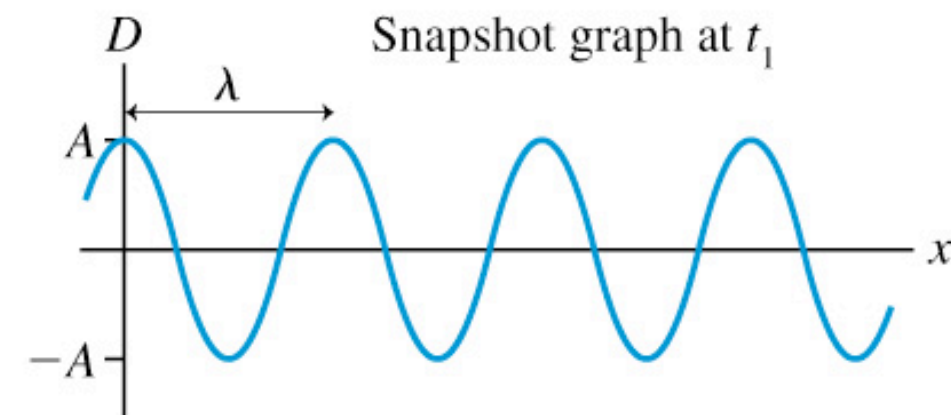


$$D(x, t) = A \sin(kx - \omega t + \phi_0)$$

(sinusoidal wave traveling in the positive x -direction)



If x is fixed, $D(x_1, t) = A \sin(kx_1 - \omega t + \phi)$ gives a sinusoidal history graph at one point in space, x_1 . It repeats every T s.



If t is fixed, $D(x, t_1) = A \sin(kx - \omega t_1 + \phi)$ gives a sinusoidal snapshot graph at one instant of time, t_1 . It repeats every λ m.

- Set wave in motion by $x \rightarrow (x - vt)$

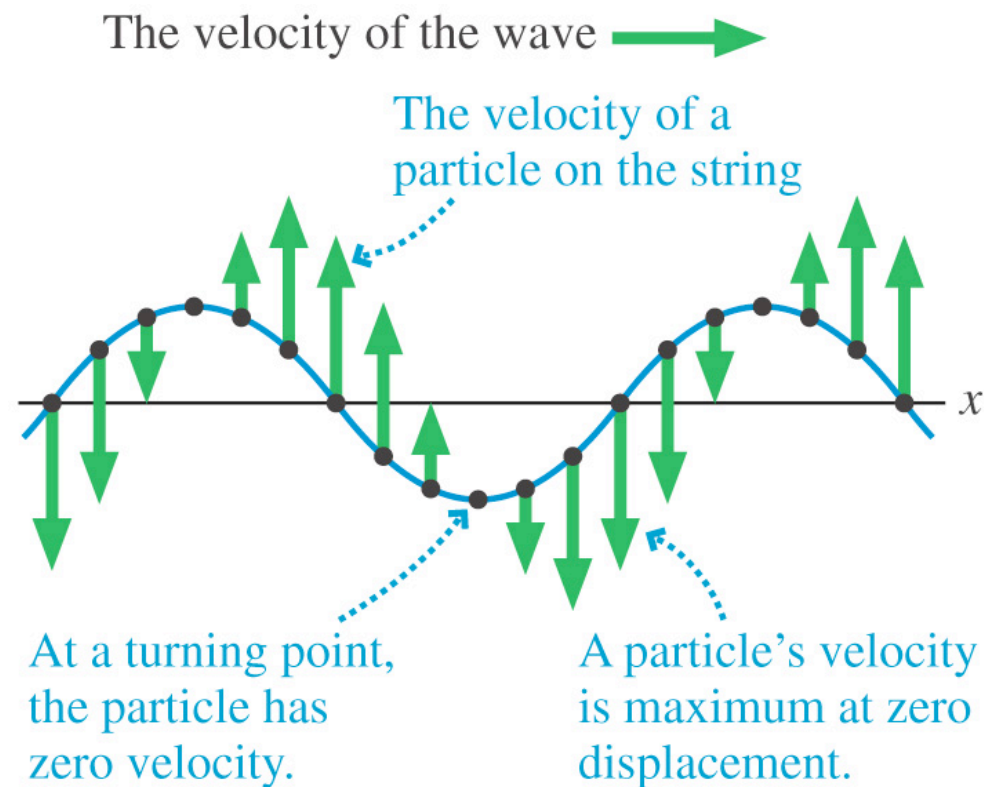
$$D(x, t) = A \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right) + \phi_0\right]$$

wave number, $k = \frac{2\pi}{\lambda}$; $\omega = \nu k$

ϕ_0 sets initial condition:

$$D(x = 0, t = 0) = A \sin \phi_0$$

Waves on a string



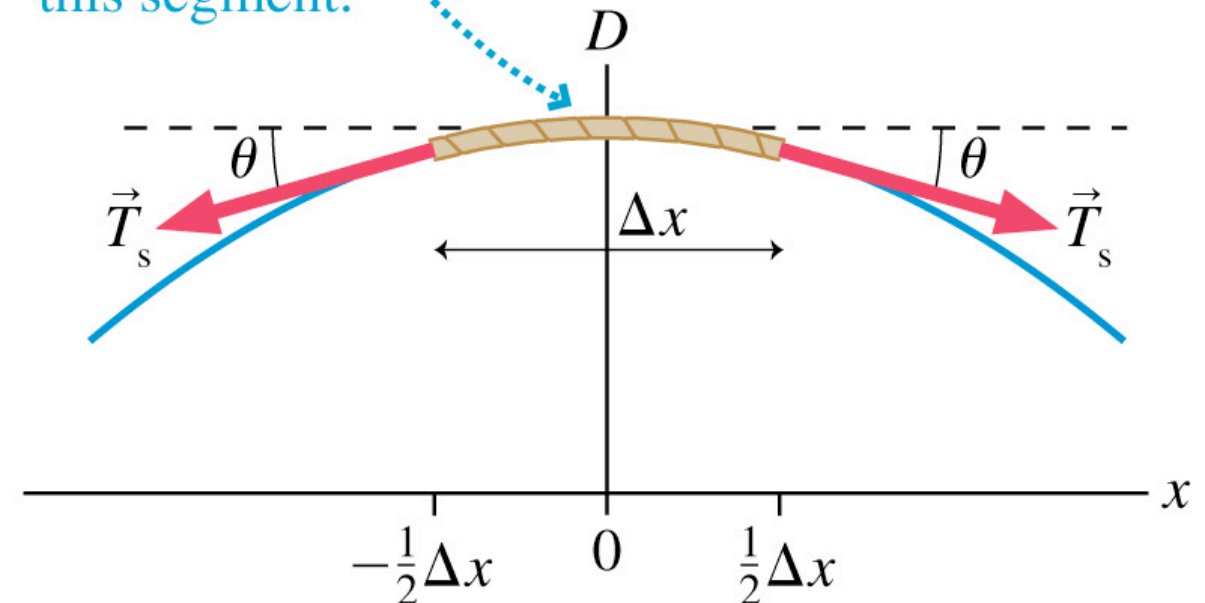
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$$y(x, t) = A \sin(kx - \omega t + \phi_0)$$

$$v_y = -\omega A \cos(kx - \omega t + \phi_0)$$

$$a_y = -\omega^2 A \sin(kx - \omega t + \phi_0)$$

A small segment of the string at the crest of the wave. Because of the curvature of the string, the tension forces exert a net downward force on this segment.



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Newton's laws applied to string

$$(F_{net})_y = ma_y = (\mu \Delta x) a_y$$

$$(F_{net})_y = 2T_s \sin \theta \approx -k^2 A T_s \Delta x$$

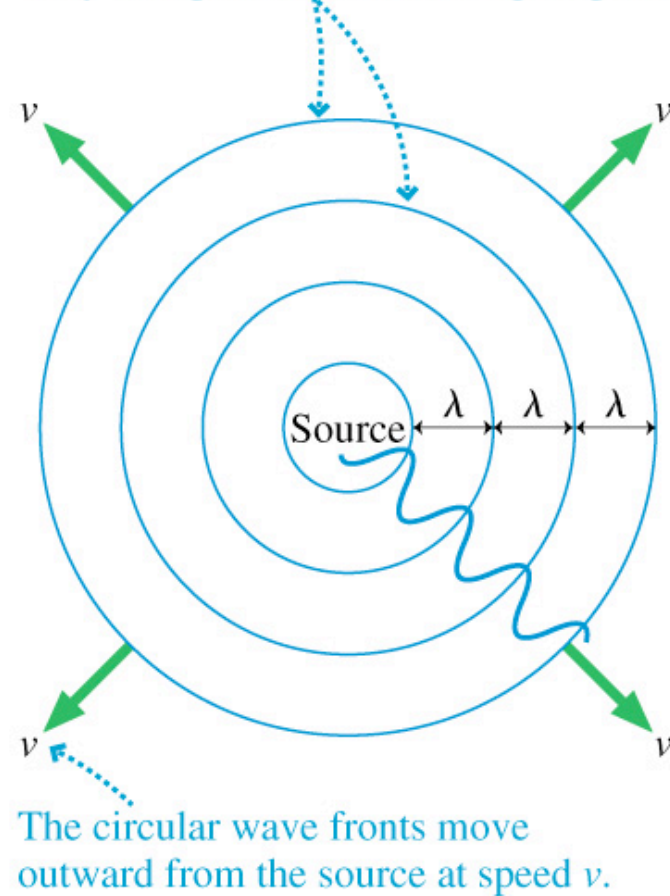
(evaluate slope of $y = A \cos(kx)$)

$$\Rightarrow v = \sqrt{\frac{T_s}{\mu}} \quad (\text{independent of } A/\text{shape})$$

2D/3D waves

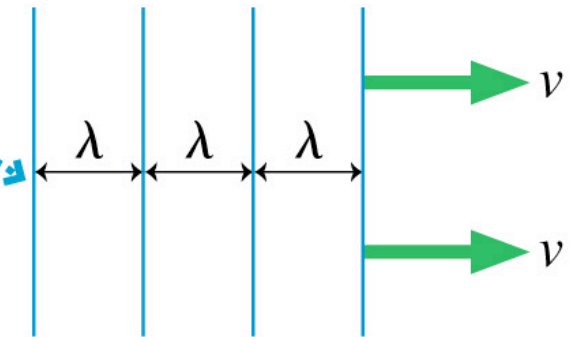
(a)

Wave fronts are the crests of the wave. They are spaced one wavelength apart.



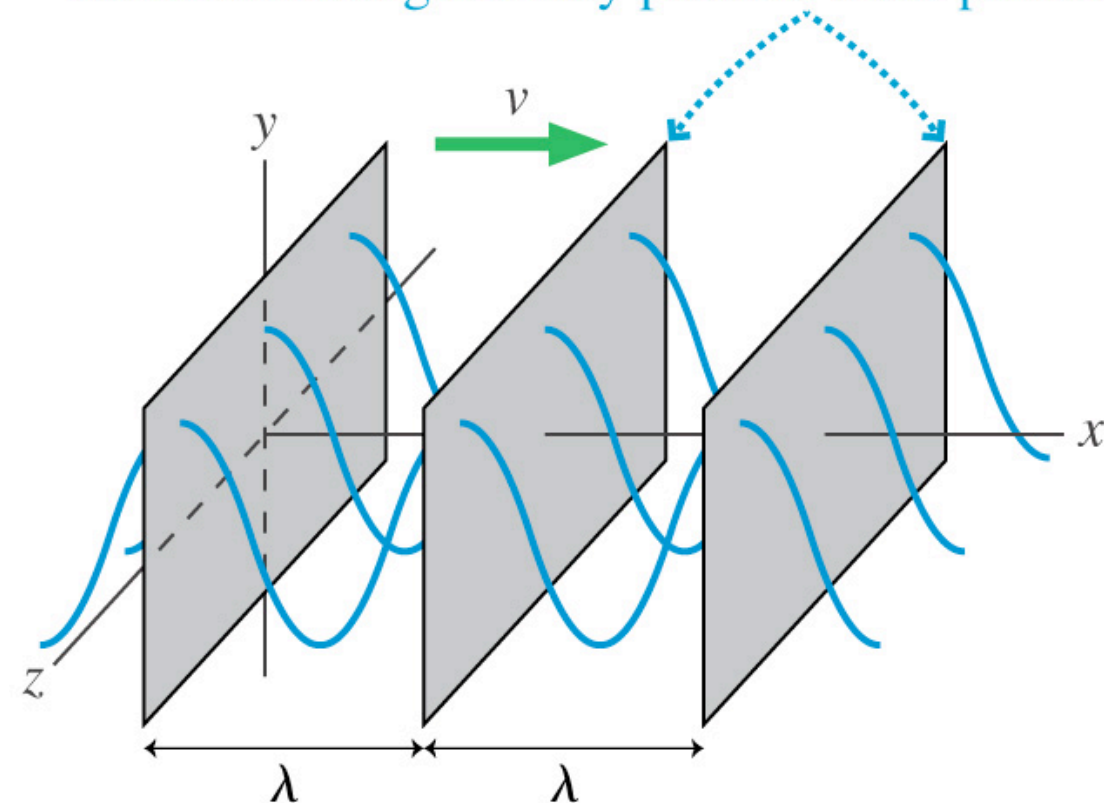
(b)

Very far away from the source, small sections of the wave fronts appear to be straight lines.



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Very far from the source, small segments of spherical wave fronts appear to be planes. The wave is cresting at every point in these planes.



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- 2D circular waves: wavefronts (lines locating crests), small section appear as straight lines far away
- 3D spherical waves...appear as planes far away, described by $D(x, t)$ (same at every point in yz plane)

2D/3D waves

$$D(r, t) = A(r) \sin(kr - \omega t + \phi_0)$$

with $A(r)$ decreasing with r

Phase and phase difference

$$\text{phase, } \phi = kx - \omega t + \phi_0$$

$$D(x, t) = A \sin \phi$$

- wavefronts are surfaces of same displacement constant phase

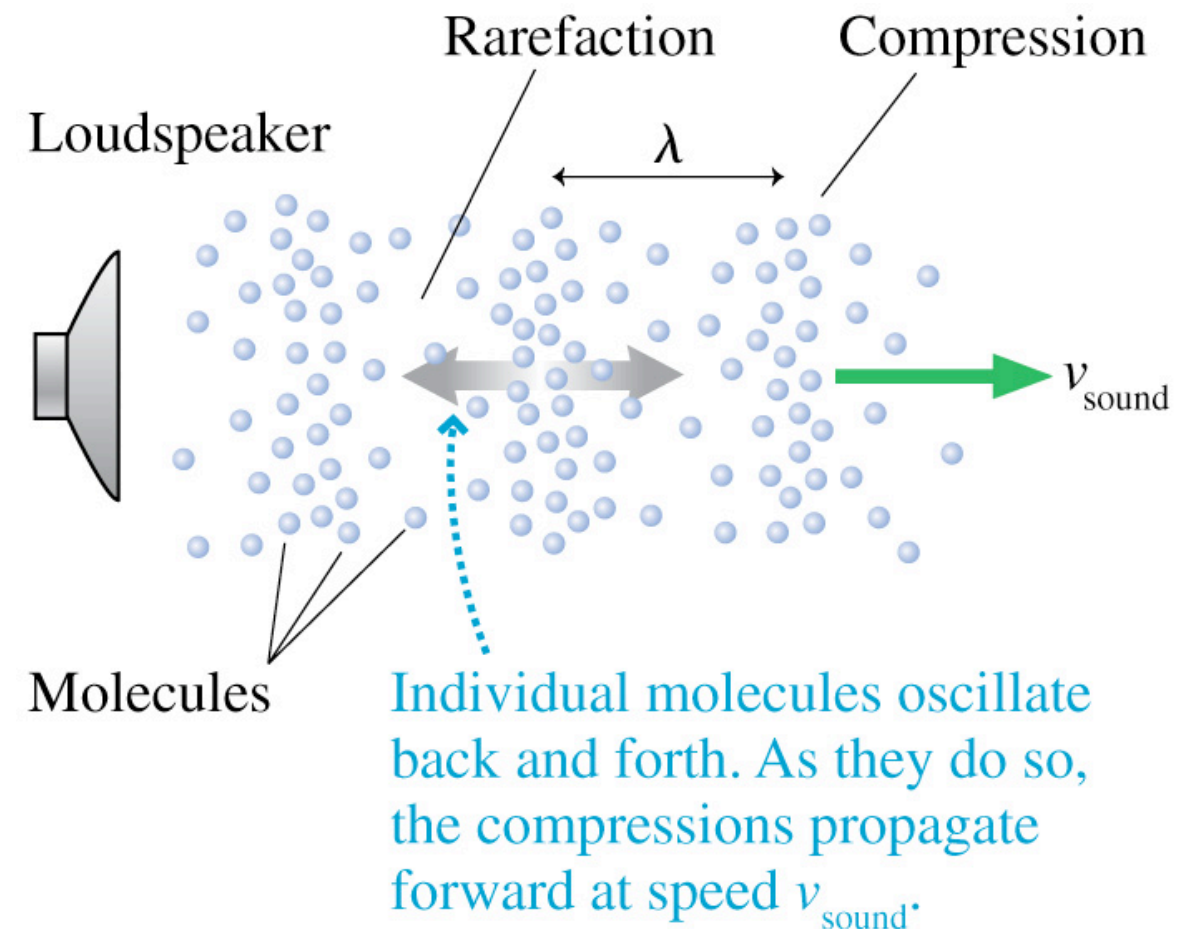
$$\text{phase difference, } \Delta\phi = 2\pi \frac{\Delta x}{\lambda}$$

$\Delta\phi = 2\pi$ between adjacent wavefronts
(separated by λ)

Sound waves

v_{sound} in air at $20^\circ = 343 \text{ m/s}$
(larger in liquid/solid)

- human ears: 20 Hz to 20 k Hz
- ultrasound: $> 20 \text{ k Hz}$



Electromagnetic (EM) waves

- oscillations of EM field, can travel in vacuum
e.g. light from stars

$$v_{light} = c = 3 \times 10^8 \text{ m/s in vacuum}$$

$$(\gg v_{sound})$$

- visible spectrum: 400 nm (violet/blue to 700 nm (orange/red)

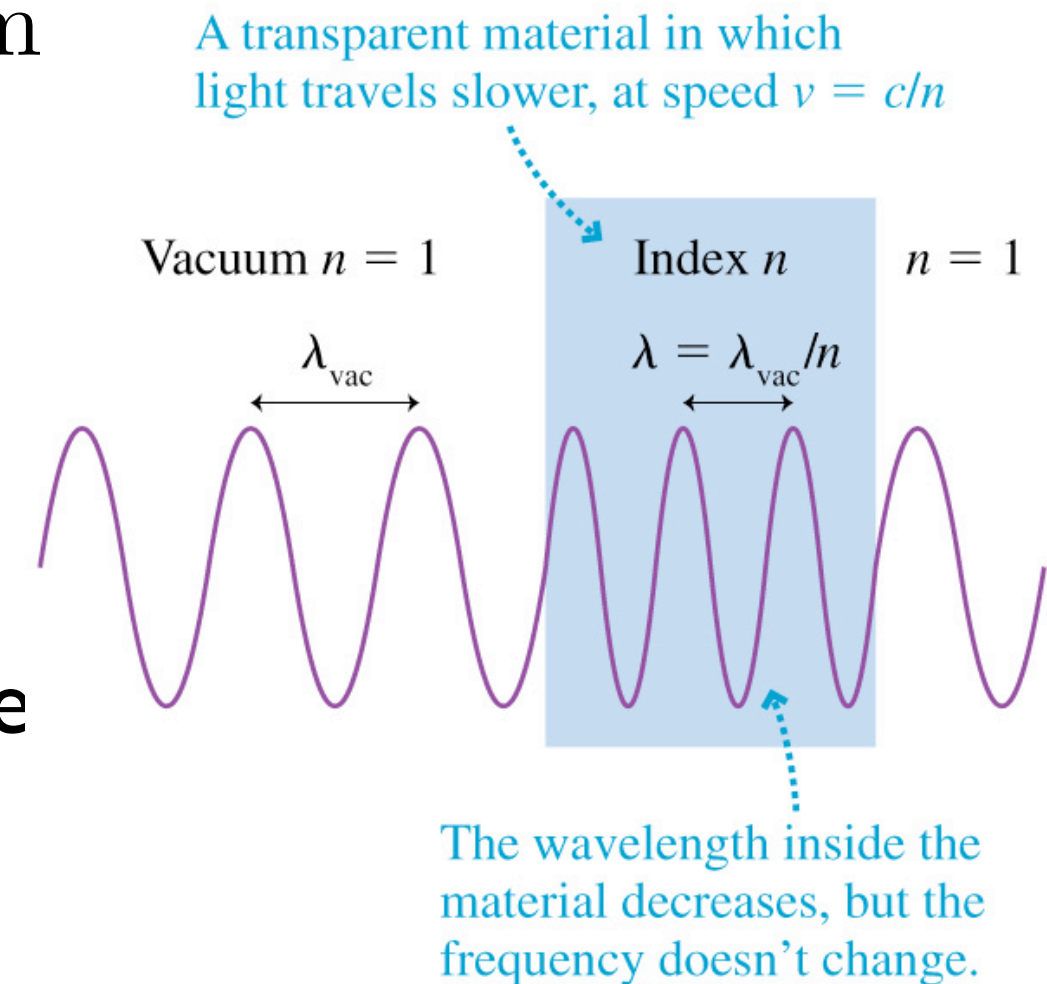
$$\ll \lambda_{sound} \Rightarrow f_{light} \gg f_{sound}$$

- EM spectrum: visible + higher frequencies (UV/X rays) + lower frequencies (IR/micro/radio waves)

- index of refraction (light slowed down):

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in material}} = \frac{c}{v}$$

- frequency does not change (e.g., sound wave hitting water):
- $$f_{vac.} \left(= \frac{c}{\lambda_{vac.}} \right) = f_{mat.} \left(= \frac{v_{mat.}}{\lambda_{mat.}} \right)$$
- $$\Rightarrow \lambda_{mat.} < \lambda_{vac.}$$



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