National University of Computer & Emerging Sciences – FAST

School of Computer Science

Course Code : NS 1001

Course Title : Applied Physics

Instructor: Engr. Muhammad Ahsan

Khan

Summer Semester 2023

Contents

- Waves & Type of Waves

- Properties of Wave

  (Frequency, Amplitude, Phase, Wavelength)

- Mathematical Representation of a Wave

Visualize this image and tell what happens?

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Visualize this image too and tell what happens?

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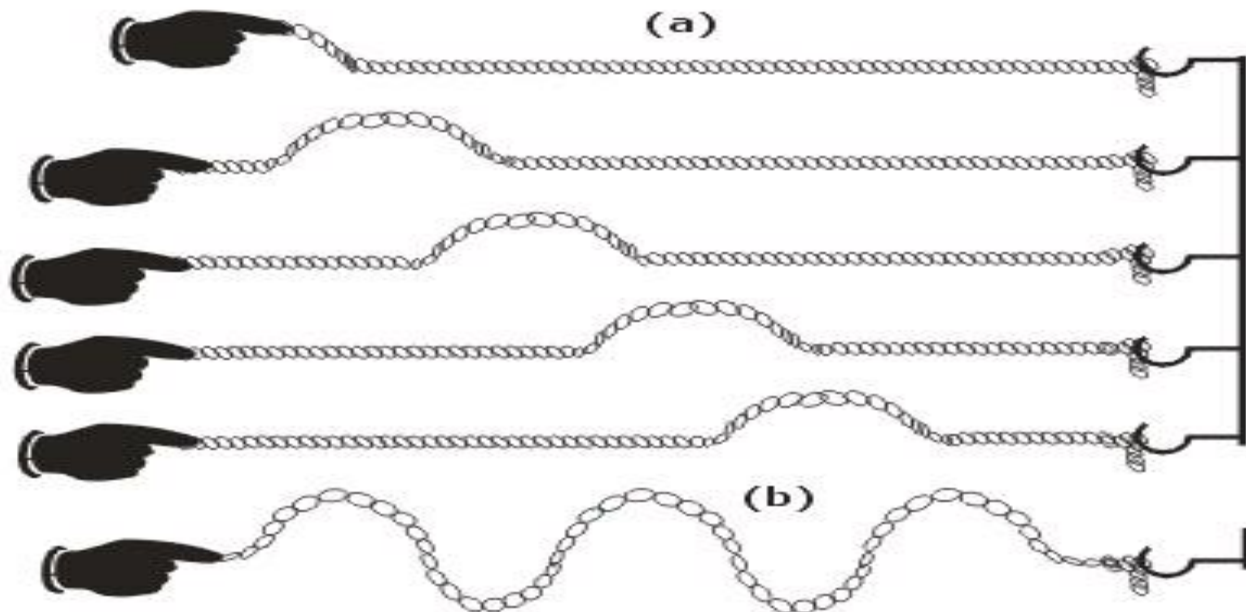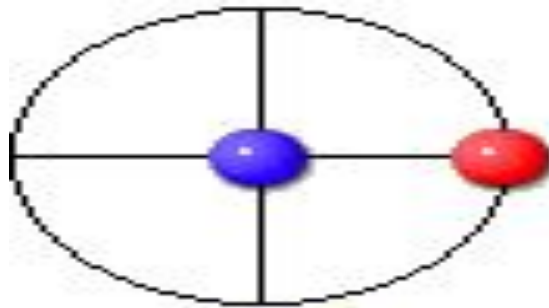
Q…What is a Wave?
Ans…Wave is… pattern of motion of particles of the medium which transport disturbance without transporting the medium

(a)

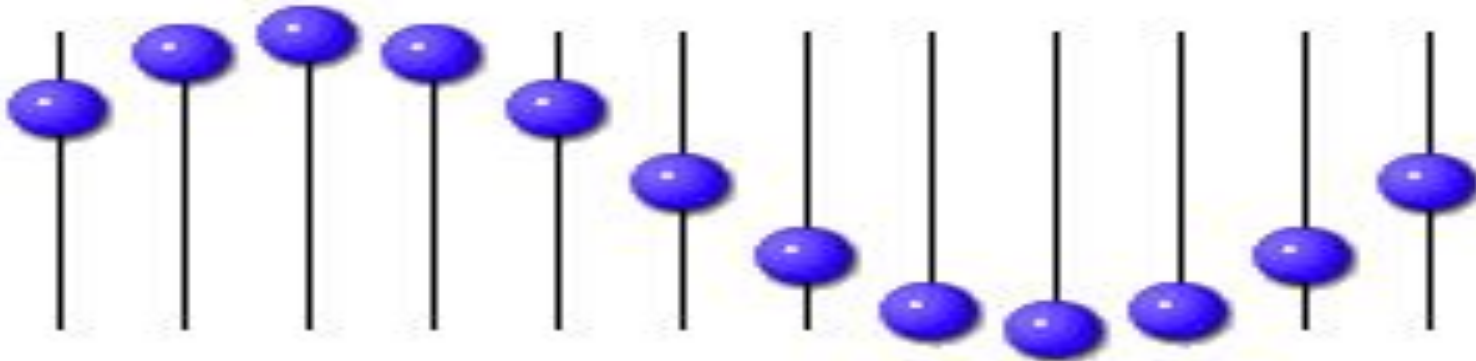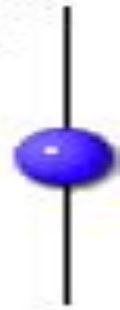(b)

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Motion of Particles in the Medium

θ : angular distancement
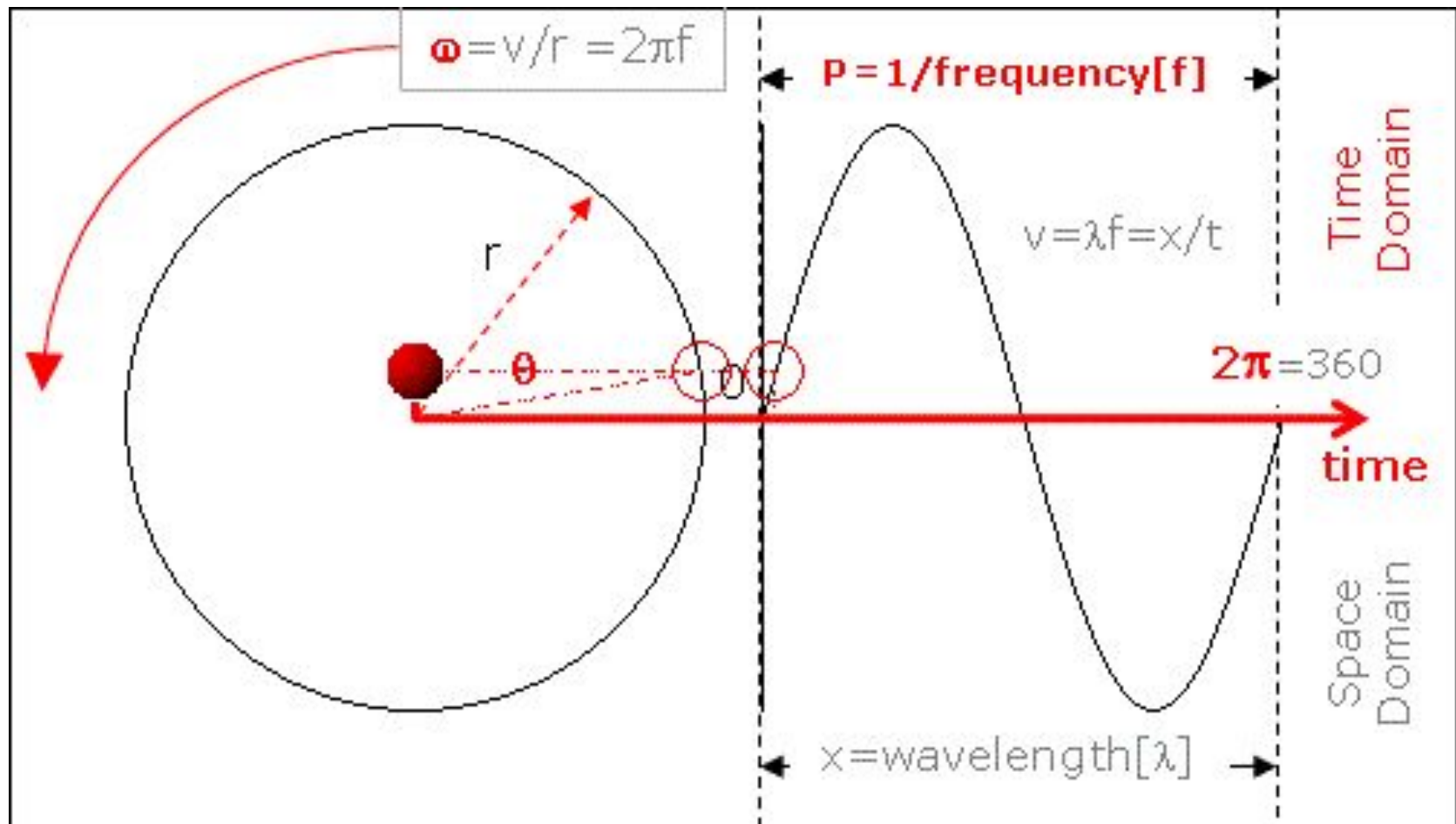ω : angular velocity (angular frequency)
t : time
$\theta = \omega t$
$y(t) = \sin(\theta) = \sin(\omega t)$

It is a sinusoidal graph because particles oscillate according to the "sine function"

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Formation of Sinusoidal Wave

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Types of Waves

1. MECHANICAL WAVES

2. ELECTROMAGNETIC

    WAVES(EMW)

3. MATTER WAVES

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Mechanical Waves

● These waves are most familiar because we encounter them almost constantly; common examples include water waves, sound waves.

● All these waves have **two central features**:

1. They are governed by Newton's laws,

2. and they can exist only within a material medium, Examples: water, air, and rock.

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ELECTROMAGNETIC WAVES

- The disturbance of Electric and Magnetic Field is transported.

- These waves require no material medium.

- Examples include visible and ultraviolet light, radio and television waves, microwaves, x rays, and radar waves.

- All electromagnetic waves travel through a vacuum at speed $c = 299\ 792\ 458$ m/s.

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Matter Waves

- Although these waves are commonly used in modern technology, they are probably very unfamiliar to you.

- These waves are associated with electrons, protons, and other fundamental particles, and even atoms and molecules. Because we commonly think of these particles as constituting matter, such waves are called matter waves.(study in modern physics)

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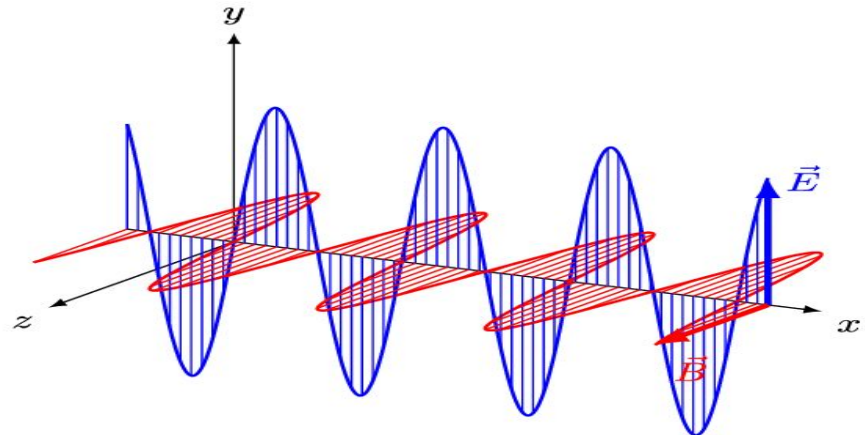
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Classification of Waves

On the basis of Medium

Mechanical waves: require medium to travel
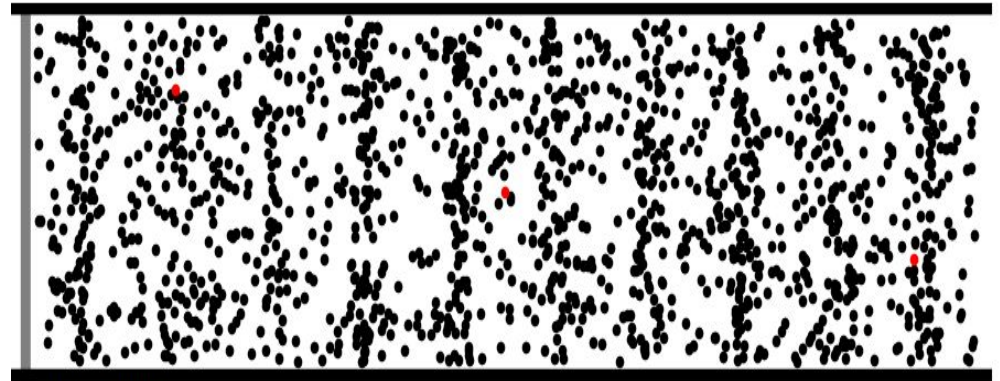
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Electromagnetic waves:
do not require medium to travel.
Travel in free space

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Classification of Waves

On the basis of vibration of particles (in material/mechanical wave)

- Transverse Waves

- Longitudinal Waves

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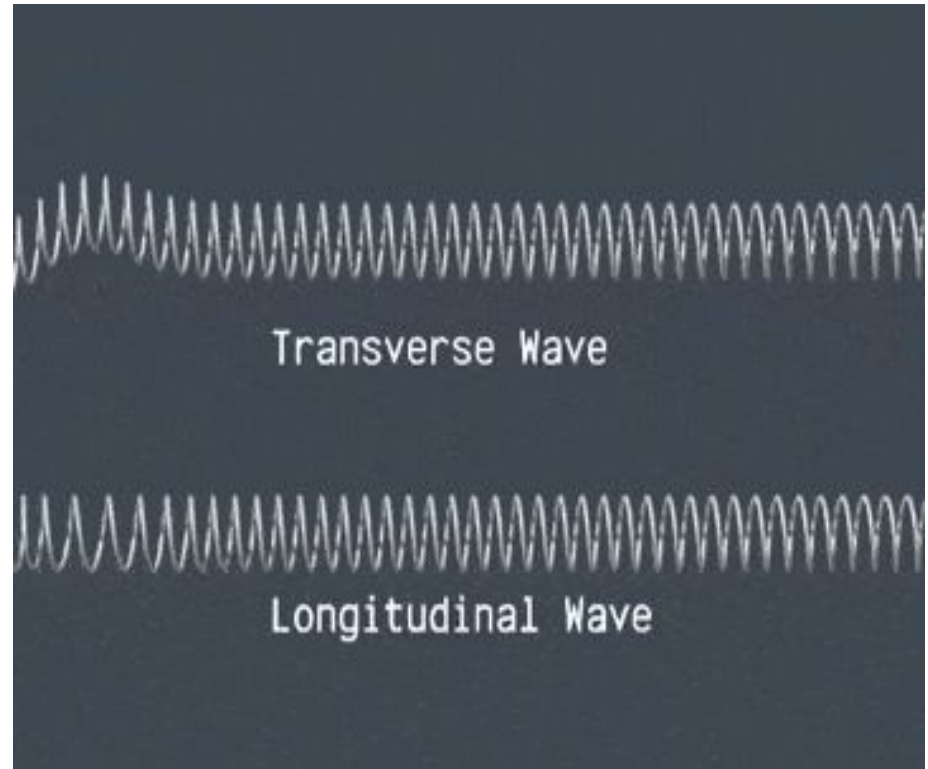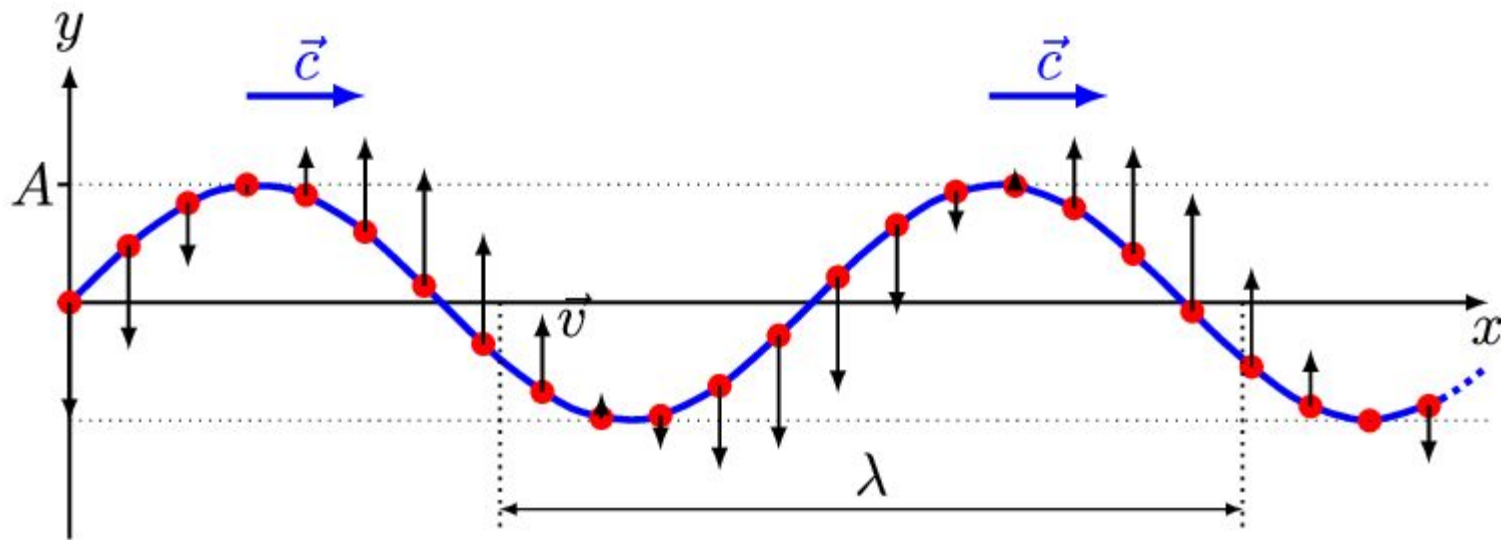
Transverse Waves

- The waves in which particles of the medium vibrates perpendicular to the direction of propagation of wave are said to be transverse waves.

- It travels in the form of cres and trough.
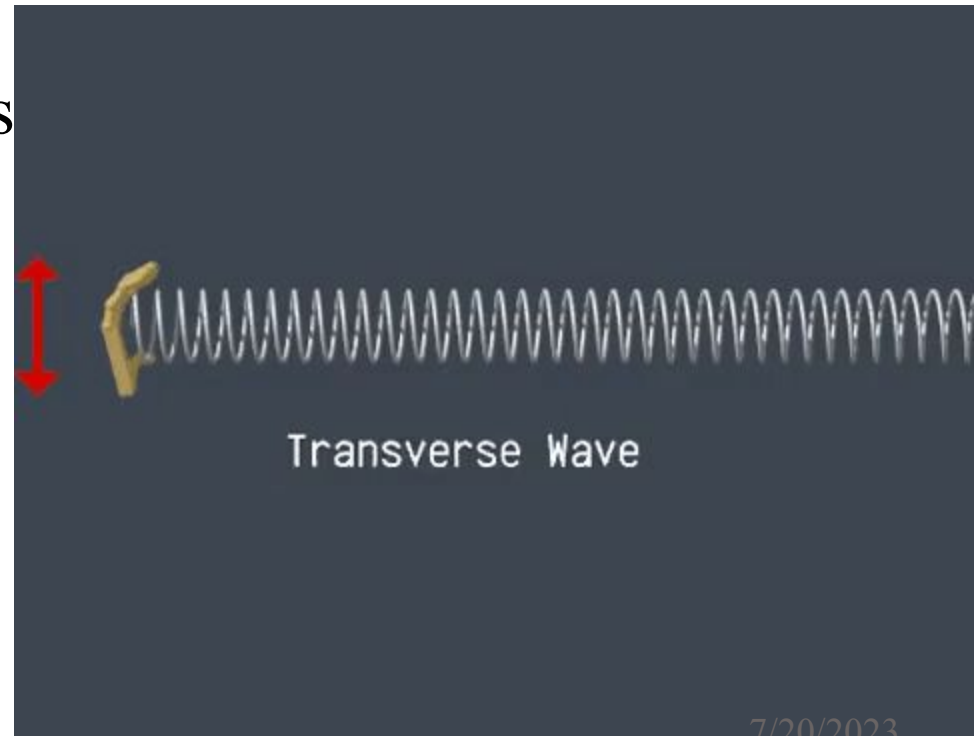
Transverse Wave

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Transverse Waves(TW) …Cont'd

Limitation for the propagation of TW:

- It transmits **only** in the medium having **rigidity** , means in solid and on the surface of liquids **except gases.**

- There is **no effect** on Temperature and Pressure of the Medium while the transverse waves is being processed on it(medium).

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Parameters of TW

- Amplitude (~A)

- Frequency(~ $\nu_{(neu)}$

- Time Period(~ T)

- Wavelength(~λ)

- Crest & Trough

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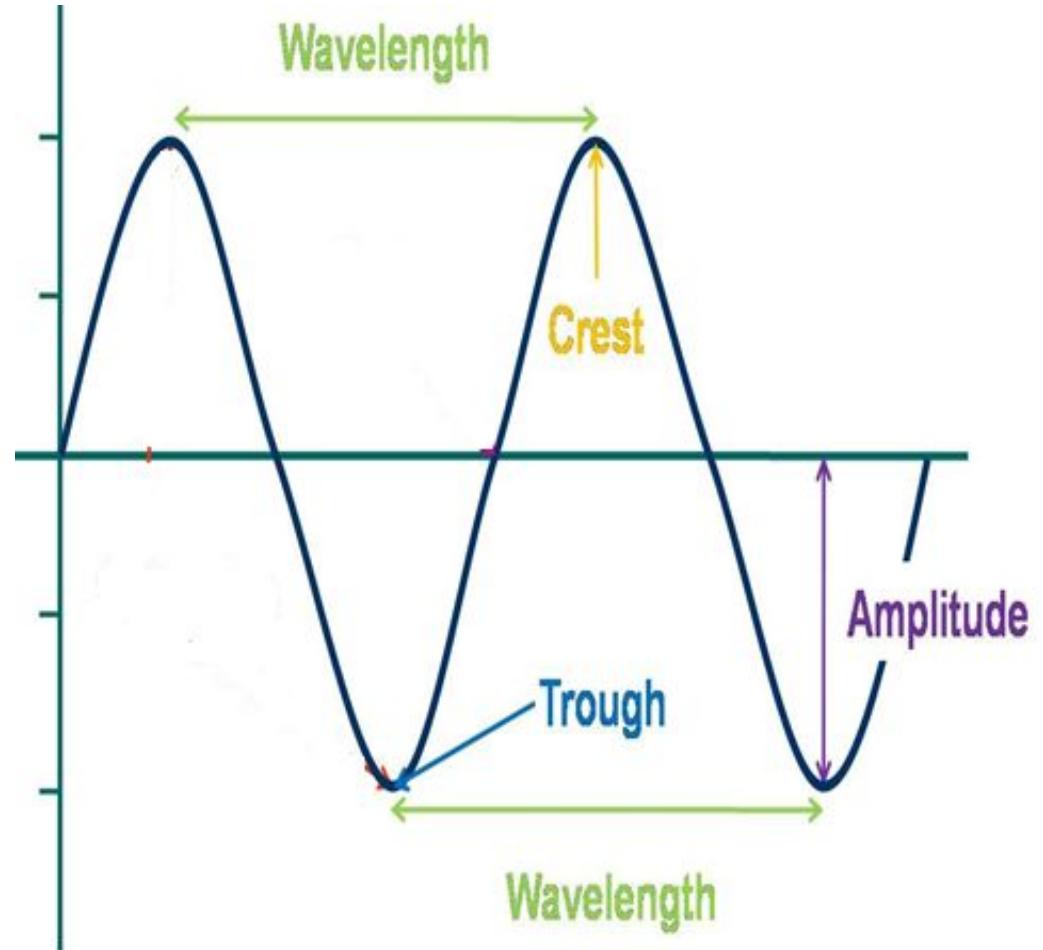
Longitudinal Waves

- Waves in which particles of the medium vibrates in the same direction of propagation of the wave are said to be longitudinal waves.

- It travels in the form of compression and rarefaction.

Longitudinal Wave

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Longitudinal Waves (LW) …Cont'd

direction of coil's
back and forth motion

impulse transmitted
to coil at this end

direction of
wave's propagation

area of increased pressure propagates through coil

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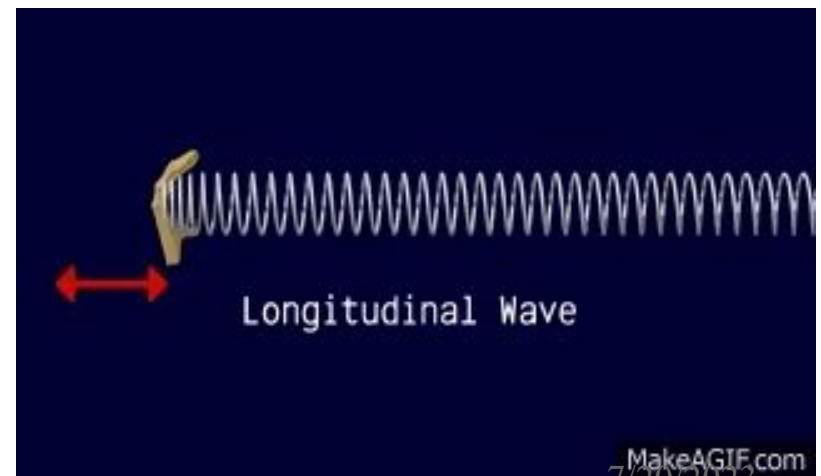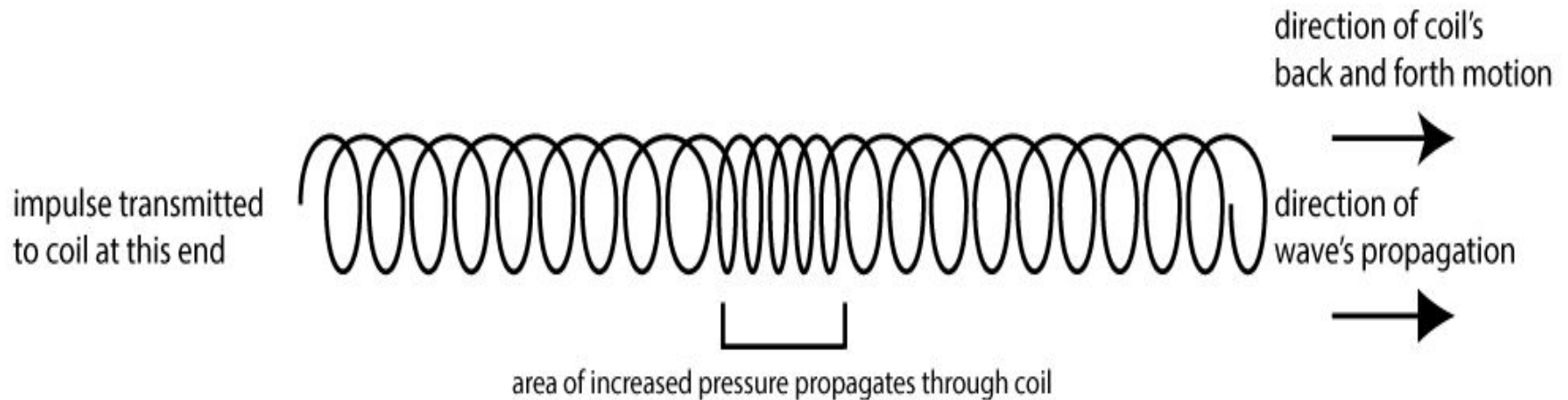
Longitudinal Waves (LW) …Cont'd

- It travels in all types of medium i.e, solid, liquid and gases.

- Temperature and Pressure of the Medium rises when the longitudinal waves is being processed on it.

Parameters of LW

- Amplitude (~A)

- Frequency(~ $\nu_{(neu)}$)

- Time Period(~ T)

- Wavelength(~λ)

- Compression & Rarefaction

Longitudinal Wave

Wavelength

Amplitude

Compression   Rarefaction   Compression

Displacement
of air
molecules

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Combination of Transverse and Longitudinal Waves

- Some waves in nature exhibit a combination of transverse and longitudinal displacements.

- Surface water waves are a good example.

- Note that in this disturbance has both transverse and longitudinal waves.

Velocity of propagation

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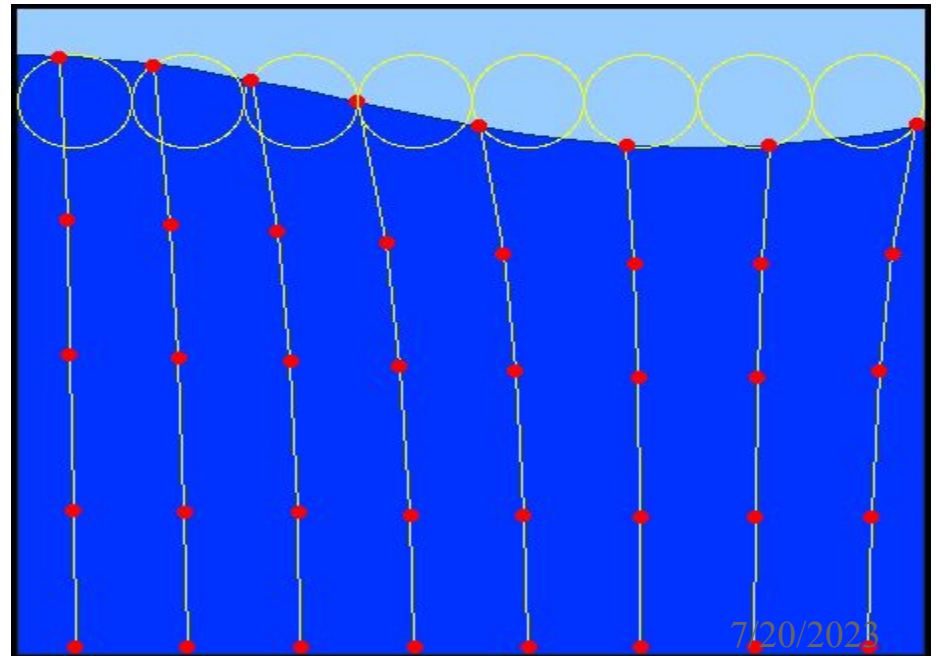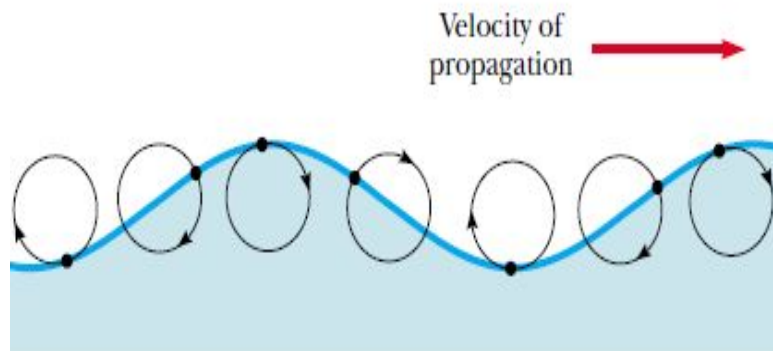
One Dimensional Pulse and a Wave Function

- We need a function that gives the shape of the wave

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Pulse $\vec{v}$

Sinusoidal wave $\vec{v}$

(a)

(b)

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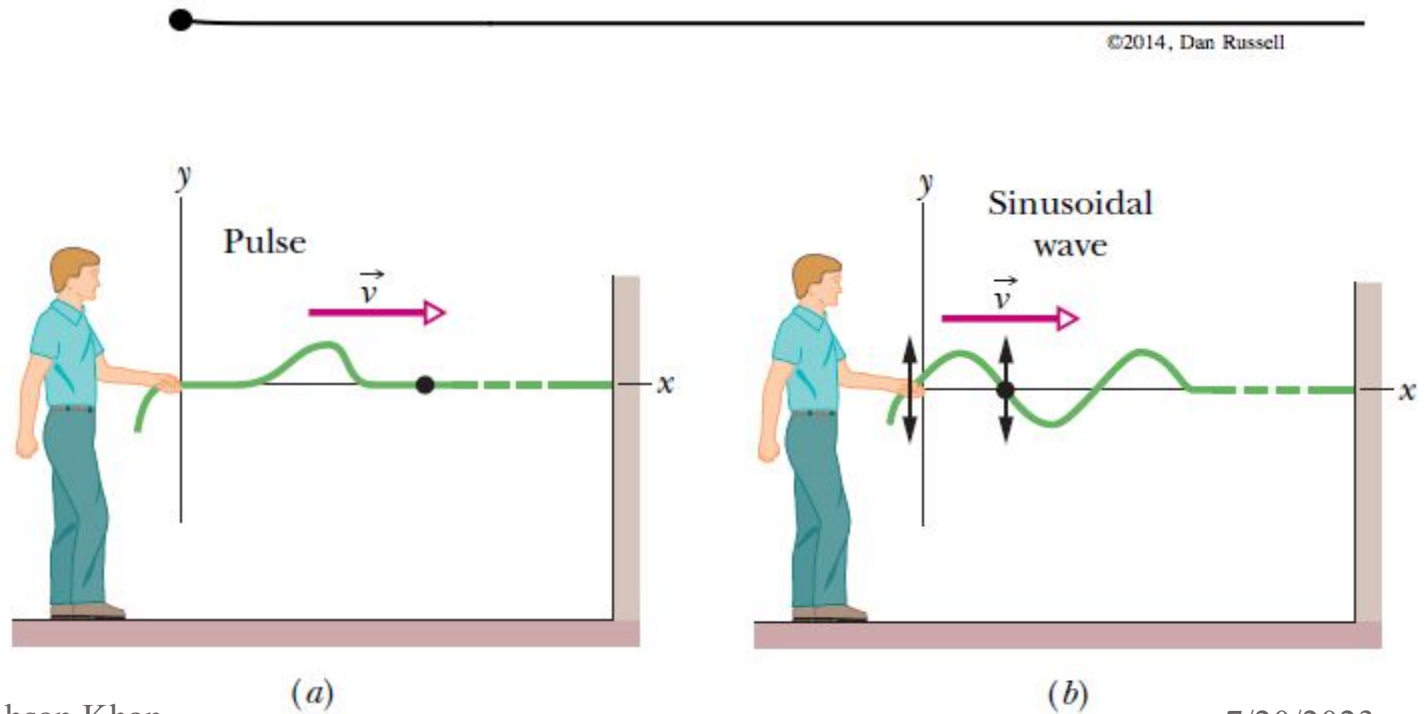
One Dimensional Pulse and a Wave Function
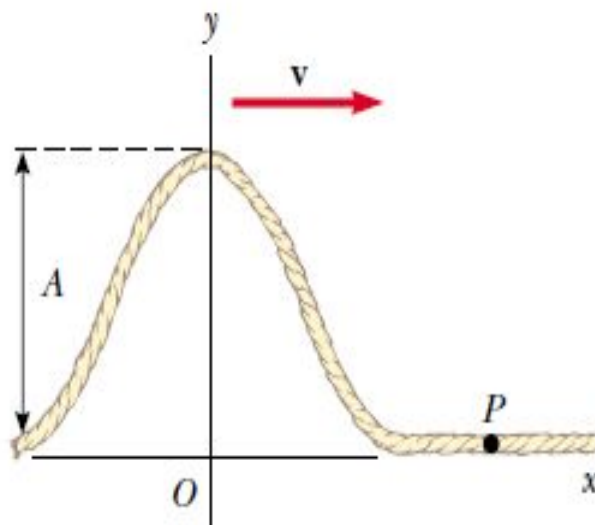
(a) Pulse at $t = 0$
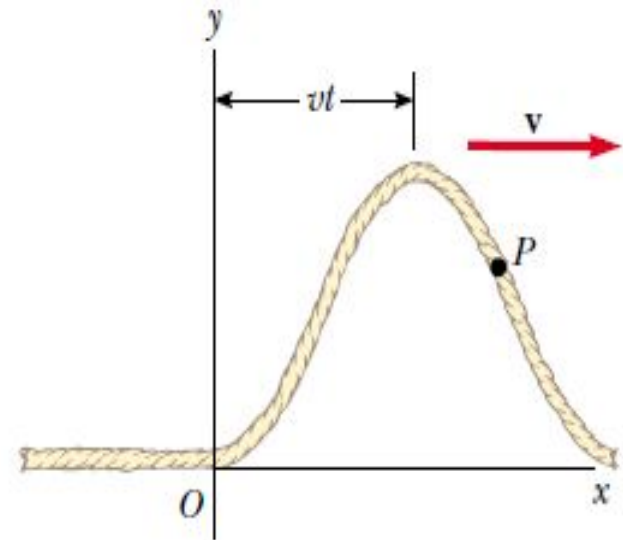
(b) Pulse at time t

A one-dimensional pulse traveling to the right with a speed v. (a) At $t = 0$, the shape of the pulse is given by $y = f(x)$. (b) At some later time t, the shape remains unchanged and the vertical position of an element of the medium any point P is given by $y = f(x - vt)$.

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Wave Function

- To completely describe a wave on a string (and the motion of any element along its length), we need a function that gives the shape of the wave.

- y is the perpendicular displacement , x is the horizontal distance covered by wave in time t.

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Wave Function

Consequently, an element of the string at x at this time has the same y position as an element located at $x - vt$ had at time $t = 0$:

$$y(x, t) = y(x - vt, 0)$$

In general, then, we can represent the transverse position y for all positions and times, measured in a stationary frame with the origin at O, as

$$y(x, t) = f(x - vt)$$ **Pulse traveling to the right**

Similarly, if the pulse travels to the left, the transverse positions of elements of the string are described by

$$y(x, t) = f(x + vt)$$ **Pulse traveling to the left**

The function y, sometimes called the **wave function,** depends on the two variables x and t. For this reason, it is often written $y(x, t)$, which is read "y as a function of x and t."

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Example Problem 1

- Pulse moving to the Right:

A pulse moving to the right along the x axis is represented by the wave function

$$y(x, t) = \frac{2}{(x - 3.0t)^2 + 1}$$

where x and y are measured in centimeters and t is measured in seconds. Plot the wave function at $t = 0$, $t = 1.0$ s, and $t = 2.0$ s.

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Example Problem 1

- Pulse moving to the Right:

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Example Problem 1

- ## Pulse moving to the Right:

A pulse moving to the right along the x axis is represented by the wave function

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where x and y are measured in centimeters and t is measured in seconds. Plot the wave function at $t = 0$, $t = 1.0$ s, and $t = 2.0$ s.

Solution First, note that this function is of the form $y = f(x - vt)$. By inspection, we see that the wave speed is $v = 3.0$ cm/s. Furthermore, the maximum value of y is given by $A = 2.0$ cm. (We find the maximum value of the function representing y by letting $x - 3.0t = 0$.) The wave function expressions are

$$y(x, 0) = \frac{2}{x^2 + 1} \qquad \text{at } t = 0$$

$$y(x, 1.0) = \frac{2}{(x - 3.0)^2 + 1} \qquad \text{at } t = 1.0 \text{ s}$$

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$$y(x, 2.0) = \frac{2}{(x - 6.0)^2 + 1} \qquad \text{at } t = 2.0 \text{ s}$$

We now use these expressions to plot the wave function versus x at these times. For example, let us evaluate $y(x, 0)$ at $x = 0.50$ cm:

$$y(0.50, 0) = \frac{2}{(0.50)^2 + 1} = 1.6 \text{ cm}$$

Likewise, at $x = 1.0$ cm, $y(1.0, 0) = 1.0$ cm, and at $x = 2.0$ cm, $y(2.0, 0) = 0.40$ cm. Continuing this procedure for other values of x yields the wave function shown in Figure **a**. In a similar manner, we obtain the graphs of $y(x, 1.0)$ and $y(x, 2.0)$, shown in Figure **b** and **c** respectively. These snapshots show that the pulse moves to the right without changing its shape and that it has a constant speed of 3.0 cm/s.

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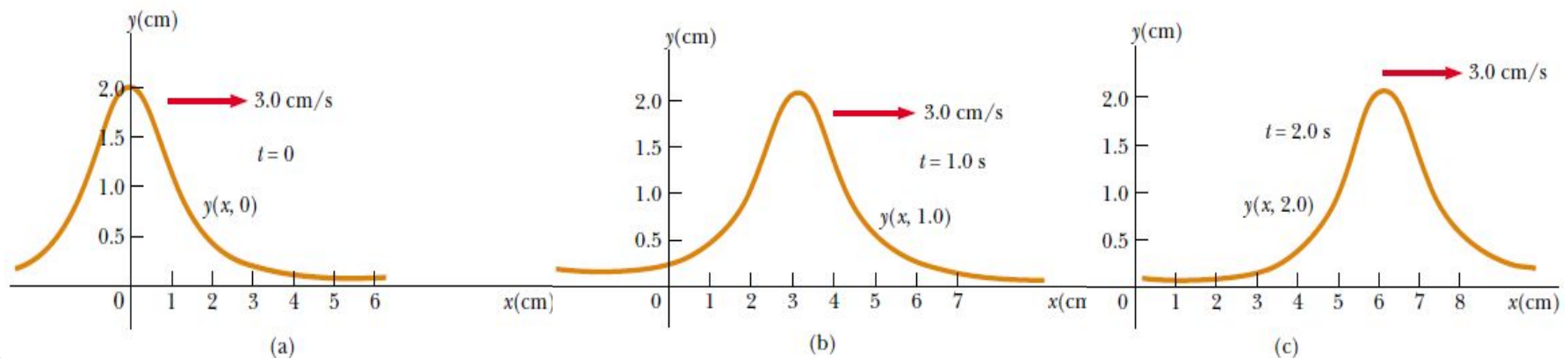
What If? **(A)** What if the wave function were

$$y(x, t) = \frac{2}{(x + 3.0t)^2 + 1}$$

How would this change the situation?

(B) What if the wave function were

$$y(x, t) = \frac{4}{(x - 3.0t)^2 + 1}$$

How would this change the situation?

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What If? (A) What if the wave function were

$$y(x, t) = \frac{2}{(x + 3.0t)^2 + 1}$$

How would this change the situation?

Answer (A) The new feature in this expression is the plus sign in the denominator rather than the minus sign. This results in a pulse with the same shape as that in Figure **a,b,c** but moving to the left as time progresses.

(B) What if the wave function were

$$y(x, t) = \frac{4}{(x - 3.0t)^2 + 1}$$

How would this change the situation?

(B) The new feature here is the numerator of 4 rather than 2. This results in a pulse moving to the right, but with twice the height of that in Figure **a,b,c**

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Sinusoidal Wave

Consider the sinusoidal wave in Figure below, which shows the position of the wave at $t = 0$. Because the wave is sinusoidal, we expect the wave function at this instant to be expressed as $y(x, 0) = A \sin ax$, where A is the amplitude and a is a constant to be determined. At $x = 0$, we see that $y(0, 0) = A \sin a(0) = 0$, consistent with Figure The next value of x for which y is zero is $x = \lambda/2$. Thus,

$$y(x, 0) = A \sin ax,$$

$$y\left(\frac{\lambda}{2}, 0\right) = A \sin a\left(\frac{\lambda}{2}\right) = 0$$

For this to be true, we must have

$$a(\lambda/2) = \pi,$$
$$\text{or } a = 2\pi/\lambda.$$

therefore
$$y(x, 0) = A \sin\left(\frac{2\pi}{\lambda}x\right)$$

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$$y(x, 0) = A \sin\left(\frac{2\pi}{\lambda} x\right) \qquad \text{at t=0}$$

$$y(x, t) = A \sin\left[\frac{2\pi}{\lambda} (x - vt)\right] \qquad \text{at time "t"} \quad \text{.....equation 1}$$

we know $\qquad v = \dfrac{\lambda}{T}$

Substituting this expression for v into Equation 1

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

We can express the wave function in a convenient form by defining two other quantities, the **angular wave number** k (usually called simply the **wave number**) and the **angular frequency** ω:

$$k \equiv \frac{2\pi}{\lambda} \qquad \textbf{Angular wave number}$$

$$\omega \equiv \frac{2\pi}{T} \qquad \textbf{Angular frequency}$$

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$$k \equiv \frac{2\pi}{\lambda} \qquad \omega \equiv \frac{2\pi}{T}$$

$$y = A \sin(kx - \omega t)$$ **Wave function for a sinusoidal** ...equation 2
wave

we can express the wave speed v originally

in the alternative forms $\qquad v = \dfrac{\omega}{k}$

$$v = \lambda f$$

The wave function given by Equation 2 assumes that the vertical position y of an element of the medium is zero at $x = 0$ and $t = 0$. This need not be the case. If it is not, we generally express the wave function in the form

$$y = A \sin(kx - \omega t + \phi) \quad \text{...Equation 3}$$ **General expression for a sinusoidal wave**
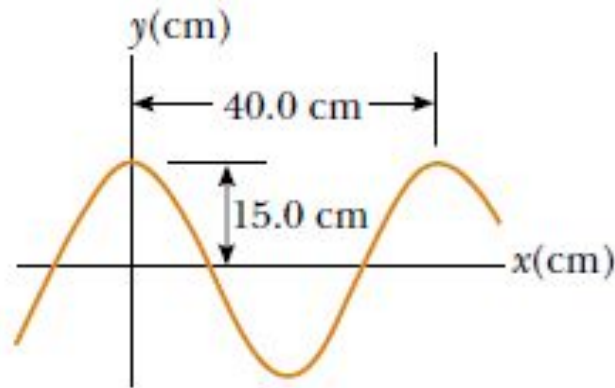
where ϕ is the **phase constant,**

This constant can be determined from the initial conditions.

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Example Problem 2

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 Figure below

A sinusoidal wave of wavelength $\lambda = 40.0$ cm and amplitude $A = 15.0$ cm. The wave function can be written in the form $y = A \cos(kx - \omega t)$.

(A) Find the wave number k, period T, angular frequency ω, and speed v of the wave.

(B) Determine the phase constant ϕ, and write a general expression for the wave function.

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Example Problem 2

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 Figure below
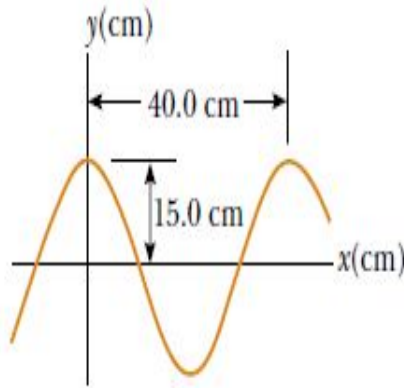

A sinusoidal wave of wavelength $\lambda = 40.0$ cm and amplitude $A = 15.0$ cm. The wave function can be written in the form $v = A \cos(kx - \omega t)$.

(A) Find the wave number k, period T, angular frequency ω, and speed v of the wave.

(B) Determine the phase constant ϕ, and write a general expression for the wave function.

Solution A Using Equations below we find the following:

$$k = \frac{2\pi}{\lambda} = \frac{2\pi \text{ rad}}{40.0 \text{ cm}} = \boxed{0.157 \text{ rad/cm}}$$

$$T = \frac{1}{f} = \frac{1}{8.00 \text{ s}^{-1}} = \boxed{0.125 \text{ s}}$$

$$\omega = 2\pi f = 2\pi(8.00 \text{ s}^{-1}) = \boxed{50.3 \text{ rad/s}}$$

$$v = \lambda f = (40.0 \text{ cm})(8.00 \text{ s}^{-1}) = \boxed{320 \text{ cm/s}}$$

Solution B Because $A = 15.0$ cm and because $y = 15.0$ cm at $x = 0$ and $t = 0$, substitution into

Equation $\qquad y = A \sin(kx - \omega t + \phi)$

$$15.0 = (15.0) \sin \phi \qquad \text{or} \qquad \sin \phi = 1$$

We may take the principal value $\phi = \pi/2$ rad (or 90°). Hence, the wave function is of the form

$$y = A \sin\left(kx - \omega t + \frac{\pi}{2}\right) = A \cos(kx - \omega t)$$

By inspection, we can see that the wave function must have this form, noting that the cosine function has the same shape as the sine function displaced by 90°. Substituting the values for A, k, and ω into this expression, we obtain

$$y = \boxed{(15.0 \text{ cm}) \cos(0.157x - 50.3t)}$$

Example Problem 3

The string shown in Figure 16.10 is driven at a frequency of 5.00 Hz. The amplitude of the motion is 12.0 cm, and the wave speed is 20.0 m/s. Determine the angular frequency ω and wave number k for this wave, and write an expression for the wave function.

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Example Problem 3

The string shown in Figure 16.10 is driven at a frequency of 5.00 Hz. The amplitude of the motion is 12.0 cm, and the wave speed is 20.0 m/s. Determine the angular frequency ω and wave number k for this wave, and write an expression for the wave function.

Solution Using Equations below we find that

$$\omega = \frac{2\pi}{T} = 2\pi f = 2\pi(5.00 \text{ Hz}) = \boxed{31.4 \text{ rad/s}}$$

$$k = \frac{\omega}{v} = \frac{31.4 \text{ rad/s}}{20.0 \text{ m/s}} = \boxed{1.57 \text{ rad/m}}$$

Because $A = 12.0$ cm $= 0.120$ m, we have

$$y = A \sin(kx - \omega t)$$

$$= \boxed{(0.120 \text{ m}) \sin(1.57x - 31.4t)}$$

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Practice Problems

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1. At $t = 0$, a transverse pulse in a wire is described by the function

$$y = \frac{6}{x^2 + 3}$$

where x and y are in meters. Write the function $y(x, t)$ that describes this pulse if it is traveling in the positive x direction with a speed of 4.50 m/s.

2. Ocean waves with a crest-to-crest distance of 10.0 m can be described by the wave function

$$y(x, t) = (0.800 \text{ m}) \sin[0.628(x - vt)]$$

where $v = 1.20$ m/s. (a) Sketch $y(x, t)$ at $t = 0$. (b) Sketch $y(x, t)$ at $t = 2.00$ s. Note that the entire wave form has shifted 2.40 m in the positive x direction in this time interval.

3. A pulse moving along the x axis is described by

$$y(x, t) = 5.00e^{-(x + 5.00t)^2}$$

where x is in meters and t is in seconds. Determine (a) the direction of the wave motion, and (b) the speed of the pulse.

4. For a certain transverse wave, the distance between two successive crests is 1.20 m, and eight crests pass a given point along the direction of travel every 12.0 s. Calculate the wave speed

5 A sinusoidal wave on a string is described by

$$y = (0.51 \text{ cm}) \sin(kx - \omega t)$$

where $k = 3.10$ rad/cm and $\omega = 9.30$ rad/s. How far does ave crest move in 10.0 s? Does it move in the positive or ative x direction?