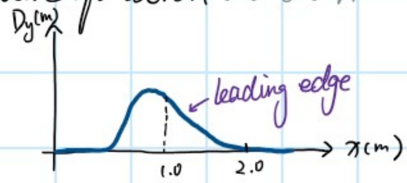
16.1 16.2

Thursday, January 10, 2019 12:49 PM

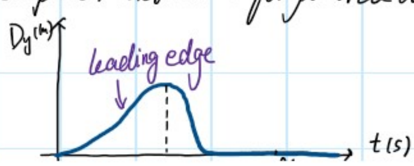
- Wave: a disturbance propagating (moving) either through a material or through empty space.
  - Wave do not carry matter from one place to another.
    The medium look the same as before a wave passed.
  - Collective phenomena ⇒ a wave can never exist at a single position.
  - { Mechanical waves (involve (temporary) displacement of particles) → require medium
    { Nonmechanical waves
- Wave a string

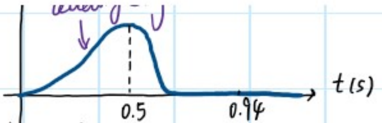
  - Wave pulse Terms like c, λ, f shouldn't be used on pulses since it's not wave & not periodic.
    - produced by waving the string
    - traveling along the string at constant speed without changing shape.
    - Not an object, have no mass.
  - The wave pulse moves horizontally, but the medium moves vertically
    (motion of wave/pulse is distinct from that of the particles in the medium)

  - { wave speed c factors: μ, T Note: Shouldn't use c, T, λ for pulses since they're not wave.
    { particles (in the medium) speed v; $\vec{D}$ displacement of particle
  - velocity of a wave pulse along a string is constant.
  - wave function (at t=0.94 s) a graphical representation of all the particle displacements at a given instant.



Displacement curve for particle located at x=0





⇨ Displacement curve is the mirror image of the wave function.

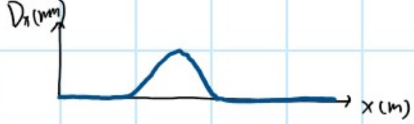
(leading edge is diffrerent ; x-axis is different)

- { **transverse waves**: medium movement is perpendicular to the pulse movement
  longitudinal waves: medium movement is parallel to the pulse movement

- wave on a spring

  - An example of longitudinal wave.

  - wave function at t_1



  Displacement curve for coil located at $x=0$

- When a particle of the string is displaced from its equilibrium position, its $\vec{v}$ & $\vec{a}$ are only determined by the initial disturbance and are independent of wave speed c.

- **The shape of of a pulse depend on v.** → speed of wave pulse

  v↑ waves are stretched out  width ↑

  v↓ waves that are compressed  width ↓

  - c is related to the strength of forces exerted by each piece (of a string) on the neighboring pieces

- T↑, c↑ ; μ↑, c↓ (See 16.6)

  - The speed c of a wave propagating a string increases with increasing tension in the string and decreases with increasing mass per unit length along the string.

tension in the string and decreases with increasing mass per unit length along the string.

- Periodic wave: the resulting wave produced by a string whose end was made to execute a periodic motion.
  - Harmonic wave: obtained by moving the end of the string so that it oscillates harmonically.
  - Wave length (λ): the distance a periodic wave repeats itself.
  - $\lambda = cT \Leftrightarrow c = \lambda f$
  - c is determined entirely by the properties of the medium

16.3 Superposition of Waves

Friday, January 11, 2019 1:46 PM

- Two waves can pass straight through each other without changing each other's shape.
- Superposition of waves: If two or more waves overlap in a medium that obeys Hooke's law, then the resulting wave function at any instant is the algebraic sum of the individual wave functions
  - Difference between object & wave: Two objects cannot occupy the same location at the same instant, while waves can.

- Interference
  - two waves overlap ⇔ waves interfere with each other.
  - Constructive interference The adding of waves of the same signs
    Destructive interference The adding of waves of opposite signs.
  - notice: waves do not interact
  - Node: a point that remains stationary in a medium through which waves move.

    ⇨ A special kind of destructive interference: two pulses with same size & shape, but of opposite algebraic signs.
- A wave contains equal amounts of kinetic and potential energy.

Proof. When two waves form a node, there's no U.

16.4 Boundary effects

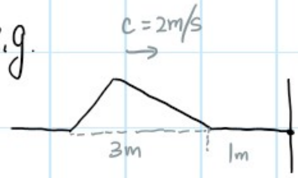
Monday, January 14, 2019 9:48 PM

- A wave pulse is reflected when reaching a boundary where the transmitting medium ends.
  - incident pulse before reaching boundary
    reflected pulse

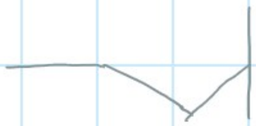
- String with fixed end

  - The fixed end will exert a downward force.
  - reflected pulse is identical in shape if no energy lost, but it will be inverted, that is, assymmetrical.

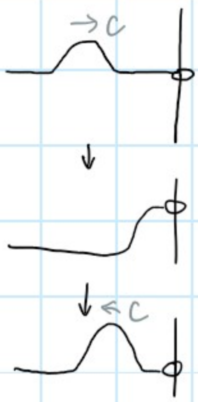
  - e.g.



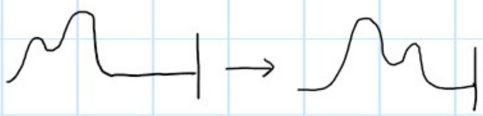
Draw the pic after reflected.



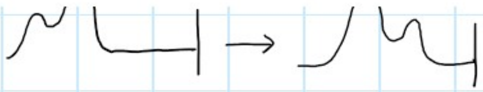
- String with free end (a light ring connected)



  - Ring move upward since there's no string particles on the right, pulling string above max height.
  - Return an identical wave pulse, but direction opposite.

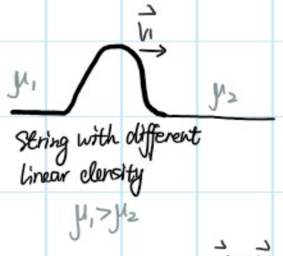


☆ leading edge should always be leading edge.

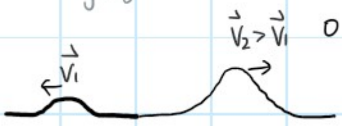


★ leading edge should always be leading edge.

- Wave pulse transmitted to different medium



  - The pulse is partially transmitted to the second medium and partially reflected.
    - The boundary partially behave like fixed end.



  - The wave length of wave changed.

    $\mu_i > \mu_f \quad \lambda_f > \lambda_i$ $\qquad c = \sqrt{\frac{T}{\mu}}$

    $\mu_i < \mu_f \quad \lambda_i > \lambda_f$

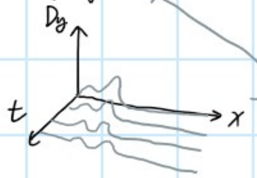
  - The transmitted wave doesn't change its shape.
  - $\mu_1 > \mu_2$, boundry acts like free end.

    $\mu_1 < \mu_2$, boundry acts like fixed end.

16.5 wave functions

Monday, January 14, 2019 10:12 PM

- $\begin{cases} D_{M_y} = f(x_M), \text{ Time-independent wave function} \\ D_y = f(x,t), \text{ Time-dependent wave function} \end{cases}$ constant shape of wave as seen from moving reference frame.



   - $x_M = x - ct$, since wave is moving at constant speed.

     $f(x_M) = f(x-ct)$

- Consider a transverse harmonic wave, $f(x) = A\sin(kx)$, the wave repeats itself over a distance λ.

  $\therefore A\sin(kx) = A\sin(k(x+\lambda)) = A\sin(kx + k\lambda)$

  $\therefore k\lambda = 2\pi$ $\qquad D = f(x,t) = A\sin(kx - \omega t + \phi)$

  $k = \frac{2\pi}{\lambda}$ m^{-1}, wave number

  $\lambda = cT \Rightarrow \lambda f = c \Rightarrow kc = \omega$

  $\therefore kc = 2\pi f = \omega$

- Because of superposition principle, any wave can be expressed in terms of sinusoidally varying waves. (harmonic waves)

- $\begin{cases} \text{traveling at } c \text{ in positive } x \text{ direction} & D_y = f(x-ct) \\ \text{traveling at } c \text{ in negative } x \text{ direction} & D_y = f(x+ct) \end{cases}$

e.g. (1) Which could represent a traveling wave?

(i) $A\cos(kx + \omega t)$ (ii) $e^{-k|x-ct|^2}$

(iii) $b(x-ct)^2 e^{-x}$ (iv) $-(b^2t - x)^2$

(2) Which can be made into a traveling wave?

(2) Which can be made into a traveling wave?

(i) $\frac{x}{1+bx^2}$ (ii) xe^{-kx} (iii) x^2

(1) All but (iii)

since e^{-x} can't be expressed as a function of $x \pm ct$

(2) All. substitute x using $x \pm ct$

☆ Don't mix the concept of "forming SHM" with this

for SHM : $F = -kx$ ...

16.6, 7 standing waves & wave speed

Monday, January 14, 2019 10:34 PM

- **Antinodes** The motion has its greatest amplitude at points halfway between nodes.

  e.g.

  6 antinodes

  7 nodes

- **Standing wave**: The pulsating stationary pattern caused by harmonic waves of the same amplitude traveling in opposite directions.
  - waves are in phrase when comparable points align.
  - form of standing wave

    $D_y = f_1(x,t) + f_2(x,t) = 2A\sin kx \cdot \cos\omega t = [2A\sin kx]\cos\omega t$ (trig identities)

    $\sin(kx) = 0$

    $\because \sin(kx) = 0 \quad \therefore k = \frac{2\pi}{\lambda}, \quad \frac{2\pi}{\lambda}x = n\pi$ (nodes)

    $\frac{2\pi}{\lambda}x = \frac{n\pi}{2}$ (antinodes)

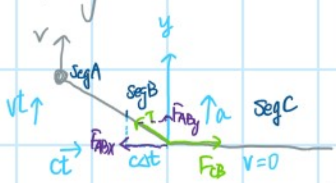
  - $D_y = 2A\sin(kx)\cos(\omega t)$

- Linear mass density

  $\mu = \frac{m}{L}$ (uniform linear object)

- $\boxed{c = \sqrt{\frac{T}{\mu}}}$ T: tension of string

  Proof:

  $T = F_{CB}$ (force are equal on string)

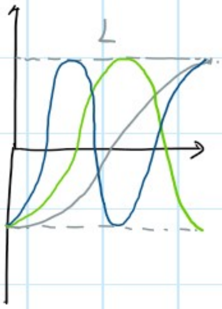
  $\frac{\Delta P_B}{\Delta t} = \frac{\mu(c\Delta t)\cdot\vec{v}}{\Delta t} = \mu c\vec{v} = \Sigma F_B$

  $\frac{F_{ABy}}{F_{ABx}} = \frac{F_{ABy}}{T} = \frac{vt}{ct} = \frac{v}{c}$

  plug in $F_{ABy} = \frac{vT}{c} = \mu c v$

  $\therefore c = \sqrt{\frac{T}{\mu}}$

- Antinode on both end. → No end is fixed. (Two free end)



Fundamental Wavelength $\lambda = 2L$

second harmonic $\lambda = L$

third harmonic $\lambda = \frac{2}{3}L$

$\lambda_n = \frac{2L}{n}$, n: number of antinodes

☆ See if one end is fixed or two end is fixed.

$\lambda_0 = 2L$

observe the picture, $\lambda_0 = 4L$

e.g. pluck the guitar string once, then repeat once.

guitar string has two fixed nodes.

∴ repeat once, antinode ++.

$\lambda \downarrow \quad c = \lambda f \quad \therefore f \uparrow$

- four times lower = a quarter of

16.8, 9

Tuesday, January 15, 2019 12:07 AM

- Energy transport of wave
  - $\Delta K = \frac{1}{2}(\mu c \Delta t)v^2 = \frac{1}{2}\mu c v^2 \Delta t$

    $\Delta U = \frac{1}{2}k\Delta l^2 = \frac{1}{2}F\Delta l$

⇒ In the limit of small displacement, the change in elastic potential energy is indeed equal to the change in kinetic energy,

- And the triangular pulse contains equal amount of kinetic and potential energy.

  - The average power (energy per unit time)

    $P_{av} = \frac{\Delta E}{\Delta t} = \frac{E_\lambda}{T}$

    - E_λ: energy stored in a length of string corresponding to one wavelength of the harmonic wave.

    $E_\lambda = \frac{1}{2}(\mu\lambda)\omega^2A^2$

    $P_{av} = \frac{\frac{1}{2}(\mu\lambda)\omega^2A^2}{T} = \frac{1}{2}A^2\mu\omega^2c$

- The wave equation
  - one-dimensional wave equation

    $$\frac{\partial^2 f}{\partial x^2} = \frac{1}{c^2}\cdot\frac{\partial^2 f}{\partial t^2}$$

    any function of the form $f(x-ct)$ or $f(x+ct)$ is a soln to this equation.

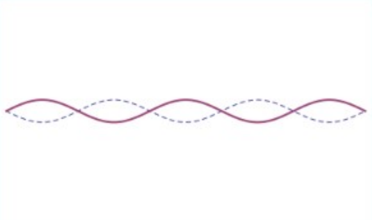
    $\frac{\partial^2 f}{\partial x^2}\uparrow \quad k$ (curvature) $\uparrow \Leftrightarrow \frac{\partial^2 f}{\partial t^2}\uparrow$

    upward k: $\frac{\partial^2 f}{\partial x^2} > 0 \Leftrightarrow \frac{\partial^2 f}{\partial t^2} > 0$

Pre-Lab

Sunday, January 13, 2019 3:01 PM

Constants | Periodic Table



The image above represents a standing wave in a string with two fixed ends. The standing wave is produced by a vibrator at one end that is vibrating with a frequency of f = 92.0 s^{-1} .

Part A

What is the number of nodes?

6

What is the number of antinodes?

5

If the length of the string L = 1.000 m , what is the wavelength λ of this standing wave?

0.400 m

$\boxed{\lambda = \frac{2L}{\text{number of antinodes}}} = 0.400m$

$\boxed{\lambda_1 = 2L}$

Based on the frequency of the vibrator, what is the **fundamental** frequency of oscillation f_1 for this string?

18.4 s^{-1}

$f = 92.0$ Hz

$\lambda = 0.400$m

$c = 92.0 \times 0.400 = 36.8$ m/s , $\lambda_1 = 2L = 2.000$ m

$f_1 = \frac{c}{\lambda_1} = 18.4$ Hz

What is the wavespeed c (note the lab manual uses v instead of c)?

36.8 m/s

If the total mass **hanging** on one end of the string that creates the tension in the string is 0.500 kg , what is the mass density (mass per unit length) μ of the string?

3.62×10^{-3} kg/m

$T = 0.500$ kg $\times 9.8$ m/s^2

$\mu = \frac{T}{v^2} = 3.62 \times 10^{-3}$ kg/m

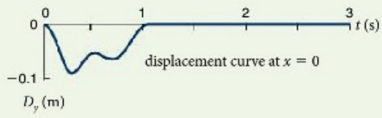
Probs

Friday, January 11, 2019   11:00 AM

★★★

2. Given the displacement curve shown in Figure 16.26 for a bead at $x = 0$ on a string as a wave with a speed of 2.0 m/s passes, draw the wave function at $t = 2.0$ s.

Figure 16.26

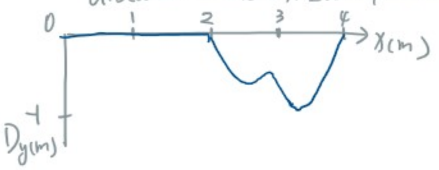


The wave passed from 0s to 1s

$\therefore$ wave length $= 2.0\,m/s \cdot 1s = 2.0\,m$

distance $= 2.0s \times 2.0 m/s = 4m$.

Note: calculate the wavelength.



★★

Which changes as the wave crosses the boundary: wavelength, frequency, both, or neither?

- wavelength
- frequency
- both
- neither

Submit   Previous Answers

✔ Correct

$c = \lambda f$

$\lambda = \sqrt{\frac{T}{\mu}}$ λ, c changes

★★★★

Constants | Periodic Table

Consider two waves X and Y traveling in the same medium. The two carry the same amount of energy per unit time, but X has one-third the amplitude of Y.

Part A

What is the ratio of their wavelengths?

$\lambda_Y/\lambda_X = 3$

$E = \frac{1}{2}A^2 w^2 \cdot \mu\lambda$

$P = \frac{\frac{1}{2}A^2 w^2 \mu\lambda}{T} = \frac{1}{2}A^2 w^2 \mu\lambda f = \frac{1}{2}A^2 \frac{c^3}{\lambda^2} \cdot \mu$

$w = \frac{2\pi}{T} = 2\pi f = 2\pi \frac{c}{\lambda}$

they're not unrelated vars!

★★★★

Constants | Periodic Table

When one end of a string is tied to a pole and the other end is moved with frequency f, the standing wave pattern shown in (Figure 1) is created.

Part A

What is the smallest frequency at which the string can be moved to produce any standing wave?

Express your answer in terms of f.

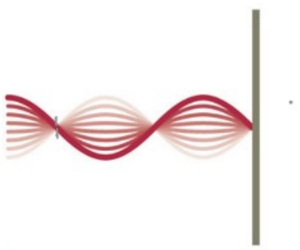
$f_{min} = \frac{f}{5}$

Submit   Previous Answers

✔ Correct

Provide Feedback

Figure   1 of 1



$\lambda_{MAX} = 4L$ (one end fixed)

$\lambda = \frac{4}{5}L$

$f_{min} = \frac{c}{4L}$ $f_{min} = \frac{f}{5}$

$f = \frac{5c}{4L}$

Inclass quiz ★★★★★

You move one end of two different strings, A and B, up and down with an identical motion. Suppose the resulting pulse travels twice as fast on string A as on string B. How does the velocity of a particle of string A compare with the velocity of a particle of string B that has the same nonzero displacement?

Inclass quiz

You move one end of two different strings, A and B, up and down with an identical motion. Suppose the resulting pulse travels twice as fast on string A as on string B. How does the velocity of a particle of string A compare with the velocity of a particle of string B that has the same nonzero displacement?

$V_A = V_B$ Motion same, f same, T same.

$\therefore \frac{2D}{T}$ equals.

Inclass quiz.

- In order for two wave pulses travelling horizontally in the same medium to create a node, select all of the following criteria that must apply.

  A. The waves must be travelling in opposite directions.

  B. The waves must be travelling in the same direction.

  C. The displacement of the waves should have opposite signs.

  D. The displacement of the waves should have the same sign.

  E. The shape of the pulses should be left-right reflected.

ACE

$c = \lambda f = \sqrt{\frac{T}{\mu}} \cdot f$

- Constants | Periodic Table

  Suppose wave pulses in an aquarium are produced by a mechanical motor that moves a bob up and down at the surface. The setup uses a 10-W motor and has a period of 1.9 s between bobs.

Part A

How much kinetic energy is in each outgoing pulse?

Express your answer with the appropriate units.

$K =$ 9.5 J

$E_{tot} = 10\mathrm{W} \times 1.9\mathrm{s} = 19\mathrm{J}$

$\therefore K = U = \frac{1}{2} E_{tot} = 9.5\mathrm{J}$

Careful

- Concept

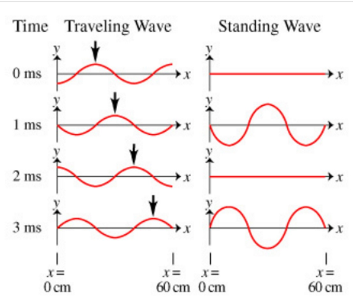
± Standing Waves on a Guitar String

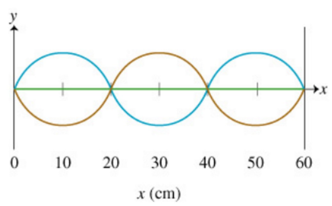
To understand standing waves, including calculation of λ and f, and to learn the physical meaning behind some musical terms.

The columns in the figure (Figure 1) show the instantaneous shape of a vibrating guitar string drawn every 1 ms. The guitar string is 60 cm long.

The left column shows the guitar string shape as a sinusoidal *traveling* wave passes through it. Notice that the shape is sinusoidal at all times and specific features, such as the crest indicated with the arrow, travel along the string to the right at a constant speed.

The right column shows snapshots of the sinusoidal *standing* wave formed when this sinusoidal traveling wave passes through an identically shaped wave moving in the opposite direction on the same guitar string. The string is momentarily flat when the underlying traveling waves are exactly out of phase. The shape is sinusoidal with twice the original amplitude when the underlying waves are momentarily in phase. This pattern is called a *standing* wave because no wave features travel down the length of the string.





How does the overtone number relate to the standing wave pattern number, previously denoted with the variable n?

- overtone number = pattern number
- overtone number = pattern number + 1
- overtone number = pattern number − 1
- There is no strict relationship between overtone number and pattern number.

overtone: any f > fundamental f

pattern number: harmonic number.

e.g. 1^{st} overtone is 2^{nd} harmonic

Correct

The overtone number and the pattern number are easy to confuse but they differ by one. When referring to a standing wave pattern using a number, be explicit about which numbering scheme you are using.

When you pluck a guitar string, you actually excite many of its possible standing waves simultaneously. Typically, the fundamental is the loudest, so that is the pitch you hear. However, the unique mix of the fundamental plus overtones is what makes a guitar sound different from a violin or a flute, even if they are playing the same note (i.e., producing the same fundamental). This characteristic of a sound is called its *timbre* (rhymes with *amber*).

A sound containing just a single frequency is called a *pure tone*. A *complex tone*, in contrast, contains multiple frequencies such as a fundamental plus some of its overtones. Interestingly enough, it is possible to fool someone into identifying a frequency that is not present by playing just its overtones. For example, consider a sound containing pure tones at 450 Hz, 600 Hz, and 750 Hz. Here 600 Hz and 750 Hz are not integer multiples of 450 Hz, so 450 Hz would not be considered the fundamental with the other two as overtones. However, because all three frequencies are consecutive overtones of 150 Hz a listener might claim to hear 150 Hz, over an octave below any of the frequencies present. This 150 Hz is called a *virtual pitch* or a *missing fundamental*.

Constants | Periodic Table

A 25.0 m steel wire and a 54.0 m copper wire are attached end to end and stretched to a tension of 145 N. Both wires have a radius of 0.450 mm, and the densities are $7.86 \times 10^3\ \mathrm{kg/m^3}$ for the steel and $8.92 \times 10^3\ \mathrm{kg/m^3}$ for the copper. (Note that these are mass densities, mass per unit volume, not linear mass densities, mass per unit length.)

Part A

How long does a wave take to travel from one end to the other end of the combination wire?

Express your answer with the appropriate units.

$\Delta t =$ 0.48 s

$$C_1 = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{145N}{5.0003\times10^{-3}kg/m}} = 170.288\ m/s$$

$$\mu_1 = 7.86\times10^3 kg/m^3 \times (0.45\times10^{-3} m)^2 \times 25.0m / 25.0m = 5.0003\times10^{-3}\ kg/m$$

$$\Delta t_1 = \frac{25m}{170.288m/s} = 0.1468\ s$$

$$C_2 = \sqrt{\frac{T}{\mu_2}} = \sqrt{\frac{145N}{5.675\times10^{-3}kg/m}} = 159.851\ m/s$$

$$\mu_2 = 8.92\times10^3 kg/m^3 \times (0.45\times10^{-3}m)^2 \times 54.0m/54.0m = 5.675\times10^{-3} kg/m$$

$$\Delta t_2 = 0.3782\ s.$$

$$\Delta t = \Delta t_1 + \Delta t_2 = 0.48\ s.$$

many choice question

A harmonic wave traveling along a light string approaches a splice to a heavier string, as shown. The wave speed in the heavier string is half that in the light string. Select all of the following correct statements.

A. The frequency of oscillation in the heavier string is twice that in the lighter string

B. The frequency of oscillation in the heavier string is half that in the lighter string

C. The frequency of oscillation in the heavier string is the same as in the lighter string

D. The wavelength in the heavier string is twice that in the lighter string

E. The wavelength in the heavier string is half that in the lighter string

F. The wavelength in the heavier string is the same as in the lighter string

CE. The force is periodic, and force is the same. $T = \frac{2\pi}{\omega} \Rightarrow f = \frac{\omega}{2\pi}$ doesn't change

What is the direction of travel of the wave represented by the time-dependent wave function $D_y(x,t)=3\sin(-5x-2t)$?

$D_y(x,t) = 3\sin[-5(x+\frac{2}{5}t)]$

in the form of $f(x+ct)$ $\therefore$ negative x direction. $c = \frac{2}{5} = 0.4\,m/s$

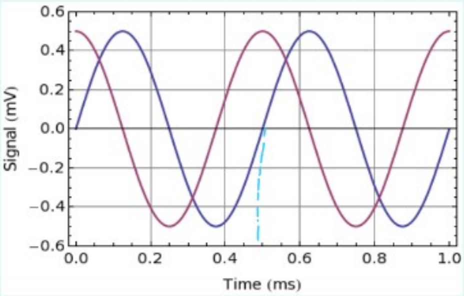
☆ Soln II.

$D_y = A\sin(kx - \omega t + \phi_i)$

$c = f\lambda = \frac{2\pi f}{k} = \frac{\omega}{k}$ $\because k=5,\ \omega=2$ $\therefore c = 0.4\,m/s$

☆☆

Consider the following graph, showing two sine-wave signals like you will see from microphones, positioned in front of a speaker, on the oscilloscope for Lab 2.



Part A

Note that the horizontal scale is in millisecond (ms) units. What is the frequency of the signals?

2000 Hz

$f = \frac{1}{T} = \frac{1}{0.5\times10^{-3}} = 2\times10^{3}\,Hz$

Part B

If the speed of sound is 314 $\mathrm{m/s}$, what is the wavelength λ of the sound wave?

0.157 m

$\lambda = \frac{c}{f} = 0.157$

Part C

The two signals differ by a phase. What is it?

1.57 rad

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$t=0$, signal $= 0.5\,mV = \sin\phi$

$\therefore \phi = \frac{\pi}{2}$

Part D

If the two microphones were at the same distance from the speaker, the two signals would be in phase: they would lie on top of each other. For the phase difference shown, what is the minimum distance between the two microphones?

3.93×10^{-2} m

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✔ Correct

phase difference $= \frac{2\pi}{\lambda}$ (path difference)

path difference $= \frac{\pi}{2} \times \frac{0.157}{2\pi} = 3.93\times10^{-2}\,m$

☆ $\frac{\text{phase difference}}{2\pi} = \frac{\text{path difference}}{\lambda}$

A guitar string is under tension and fixed at both ends (nut and bridge). If you pluck string 1 it produces a note with a frequency of 329.63 Hz. Select all of the correct statements if you push string 1 at the 3rd fret and then pluck in exactly the same way.

A. The frequency remains approximately the same
B. The frequency increases
C. The frequency decreases
D. The wave speed remains approximately the same
E. The wave speed increases
F. The wave speed decreases

first time : $\lambda_1 = 2L$

Second time : $\lambda_2 = \frac{2L}{2} = L$

c = speed of sound, which doesn't change. BD

$\therefore c = \lambda f$, $\lambda \downarrow f \uparrow$