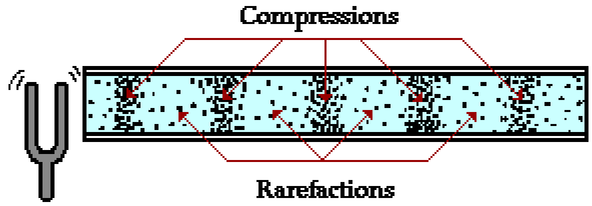
Chapter 2

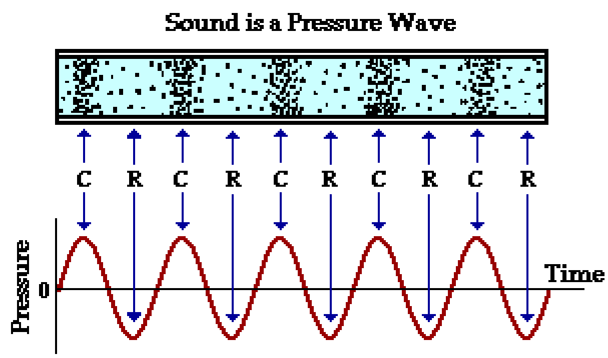
SOUND WAVES

Introduction: A sound wave (or pressure or compression wave) results when a surface (layer of molecules) moves back and forth in a medium producing a sequence of compressions "C" and rarefactions "R". Although individual molecules do not travel any appreciable distance, the disturbance travels outwards.

$\Rightarrow$ The **compression** is a region where the molecules of the medium are very close to each other and the **pressure** is **higher** than normal pressure.

$\Rightarrow$ The **rarefaction** is a region where the molecules are farther away from each other and the **pressure** is **lower** than the normal pressure





Sound propagates in the form of **longitudinal waves** through a medium. In such a wave, the particles of the disturbed medium move **parallel** to the wave velocity. The sound waves have the following categories:

i. **Audible** sound has a frequency from 20 Hz to 20,000 Hz.
ii. **Infrasonic** are the frequencies lower than 20 Hz, and
iii. **ultrasonic** are frequencies higher than 20,000 Hz.

Sound waves have the following properties:

1. They can travel through solids, liquids or gasses, but not vacuum.
2. The speed of sound is a constant for a given material at a given pressure and temperature. For example, the speed of sound in air, v_o, at 1 atmospheric pressure and 0 ^{o}C is equal to 331 m/s.
3. Speed of sound in air (v_{air}) < speed of sound in liquid (v_{liquid}) < speed of sound in solid (v_{solid}). This is mainly related to the intermolecular spaces in a substances.

4. When sound goes from low dense medium (e.g. air) into a higher dense medium (e.g. liquid) the frequency stays unchanged, the velocity increases, and thus the wavelength must increases, recall the relation $v = f\lambda$.
5. Speed of sound increases with increasing the temperature. Recall the empirical formulae:

$$v_T = v_o + 0.6\,T, \qquad T \text{ is in } ^{o}\text{C}$$

$$v_T = v_o\sqrt{\frac{T}{273}}, \qquad T \text{ is in Kelvin}$$

where $v_o = 331$ m/s.

➔ Calculate the speed of sound at 27 ºC, using two different methods.

✓ $$v_{27} = v_o + 0.6\,T = 331 + 0.6\times 27 \approx 347 \text{ m/s.}$$

✓ $$v_{27} = 331\sqrt{\frac{273+27}{273}} \approx 347 \text{ m/s.}$$

6. Speed of sound in different media is expressed as:

$$v(\text{solids}) = \sqrt{\frac{Y}{\rho}}, \qquad Y \text{ is the Young's modulus, } [Y] = \frac{\text{N}}{\text{m}^2} = \text{Pa}$$

$$v(\text{liquids or gases}) = \sqrt{\frac{B}{\rho}}, \qquad B \text{ is the Bulk's modulus, } [B] = \frac{\text{N}}{\text{m}^2} = \text{Pa}$$

The Bulk's modulus is defined as $B = -\frac{\Delta P}{\Delta V / V}$, where $\Delta V / V$ is the fractional change in the volume produced by a change in the pressure ΔP. B for liquid is more than 10^3 times greater than that of air, this is why $v_{liquid} > v_{air}$.

➔ Assuming the velocity of sound in air at 0 ºC is v_o = 331 m/s, calculate the change in the wavelength due to a frequency of f = 1000 Hz when the temperature changes from 0 ºC to 30 ºC.

✓ At 0 ºC, $$\lambda_o = \frac{v_o}{f} = \frac{331}{1000} = 0.331 \text{ m.},$$

At 30 ºC, T = 303 K, then $\lambda_{30} = \frac{v_{30}}{f} = \lambda_o\sqrt{\frac{303}{273}} = 0.349$ m.,

and the change in the wavelength is $\lambda_{30} - \lambda_o = 0.018$ m = 18 mm

➔ A man strikes a long steel rod at one end. Another man, at the other end with his ear close to the rod, hears the sound of the blow twice (once through air and once through the rod), with time interval $\Delta t = 0.1$ s between them. How long "l" is the rod? [For the steel, $Y = 2.1\text{x}10^{11}$ Pa, and the $\rho = 7.0\text{x}10^3$ kg/m^3. Speed of sound in air $v_o = 340$ m/s.]

✓ The speed of sound in the steel is $v = \sqrt{\dfrac{Y}{\rho}} = \sqrt{\dfrac{2.1\times10^{11}}{7.0\times10^3}} = \underline{5477 \text{ m/s}}$,

then

$$\Delta t = \frac{l}{v_o} - \frac{l}{v} \quad \Rightarrow \quad l = \frac{v v_o}{v - v_o}\Delta t,$$

$$\Rightarrow \quad l = \frac{5477\times340}{5477-340}\times 0.1 = \underline{36 \text{ m}}.$$

Harmonic sound waves: The harmonic displacement along x-direction, $S(x,t)$, is given by:

$$S(x,t) = S_m \cos(kx - \omega t)$$

where S_m is the maximum displacement (amplitude). The **change in pressure**, $\Delta P(x,t)$, of the longitudinal wave from its equilibrium value is given by:

$$\Delta P(x,t) = \Delta P_m \sin(kx - \omega t) \;,$$

where ΔP_m is the maximum amplitude and has the form:

$$\Delta P_m = \rho v \omega S_m$$

ρ is the volume density $(\equiv \dfrac{\text{mass}}{\text{Volume}})$. Note that $S(x,t)$ and $\Delta P(x,t)$ are out of phase by 90^o.

The average energy: ($E_{average}$, [E] = J), the average energy of the moving layer, with thickness Δx and area A, of the longitudinal wave is:

$$E_{average} = \frac{1}{2}\Delta m(\omega S_m)^2 A = \frac{1}{2}(\rho A \Delta x)(\omega S_m)^2$$

where $A\Delta x$ is the volume of the layer.

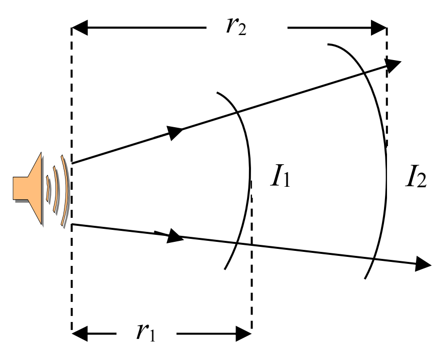
The average power: ($P = \dfrac{E_{average}}{t}$, [P] = W), transmitted in a harmonic sound wave is defined by

$$P = \frac{1}{2}\rho v(\omega S_m)^2 A$$

where $v = \dfrac{\Delta x}{t} \equiv$ wave speed .

The intensity: (I = $\dfrac{P}{A}$, [I]= $(\dfrac{\text{W}}{\text{m}^2})$), is the energy per second flowing normally through an area of 1 m^2 at the place concerned. For sound wave, it is defined as (Power/Area) $\Rightarrow$

$$\text{I} = \frac{1}{2}\rho v(\omega S_m)^2 = \frac{\Delta P_m^2}{2\rho v}$$



Because the sound waves spread out as they move away from their source, their intensity decreases with distance and obeys the inverse-square law, i.e. $\mathrm{I} \propto 1/r^2$.

The following ratio is also useful:

$$\frac{\mathrm{I}_1}{\mathrm{I}_2} = \left(\frac{r_2}{r_1}\right)^2$$

Spherical waves: At a distance *r* from spherical (point) source, the total power is distributed over the $4\pi r^2$ area of a sphere of radius *r*. Hence the intensity of the sound at this distance is:

$$\mathrm{I} = \frac{P}{4\pi r^2}.$$

➔ A point source of sound wave has average power of 1.00×10^{-6} W. What is the intensity 3.00 m away from the source ?

✓
$$\mathrm{I} = \frac{P}{4\pi r^2} = \frac{1.00\times10^{-6}}{4\pi\times3^2} = 8.84\times10^{-9}\ \mathrm{W/m^2}$$

➔ Assume that sound from a plane engine enters your ear normally with intensity of 0.05 W/m². If your ear passage has a cross-sectional area of 38 mm², how many Joules of energy per second enter your ear?

✓
$$P = IA = (0.05)(38\times10^{-6}) = 1.9\times10^{-6}\ \mathrm{J/s}.$$

Sound level: (β, [β] = dB ≡ Decibel), is defined by:

$$\beta = 10\times\log_{10}\left(\frac{\mathrm{I}}{\mathrm{I_o}}\right) \quad \Rightarrow \quad \mathrm{I} = \mathrm{I_o}\times10^{\beta/10},$$

where $\mathrm{I_o} = 10^{-12}\ \frac{\mathrm{W}}{\mathrm{m}^2}$ is the lowest audible sound (the threshold of hearing).

➔ Find the ratio of the intensities of two sound waves if the difference in their sound levels is 7 dB.

✓
$$\beta_2 - \beta_1 = 10\times\log\left(\frac{\mathrm{I}_2}{\mathrm{I_o}}\right) - 10\times\log\left(\frac{\mathrm{I}_1}{\mathrm{I_o}}\right) = 10\times\log\left(\frac{\mathrm{I}_2}{\mathrm{I}_1}\right) = 7\ \mathrm{dB}$$

This gives the ratio:

$$\frac{\mathrm{I}_2}{\mathrm{I}_1} = 10^{7/10} = \underline{5}.$$

➔ The sound level 2 m from a source is measured to be 90 dB. How far away must one be to measure a sound level of 50 dB?

✓
$$\beta_1 = 90 \text{ dB} \quad \Rightarrow \quad \mathrm{I}_1 = \mathrm{I}_o \times 10^{90/10} = 10^{-3}\,\frac{\mathrm{W}}{\mathrm{m}^2},$$
$$\beta_2 = 50 \text{ dB} \quad \Rightarrow \quad \mathrm{I}_2 = \mathrm{I}_o \times 10^{50/10} = 10^{-7}\,\frac{\mathrm{W}}{\mathrm{m}^2},$$
$$\because \frac{\mathrm{I}_1}{\mathrm{I}_2} = \left(\frac{r_2}{r_1}\right)^2 \quad \therefore \quad r_2 = r_1\sqrt{\frac{\mathrm{I}_1}{\mathrm{I}_2}} = 2\sqrt{\frac{10^{-3}}{10^{-7}}} = 200 \text{ m}.$$

Interference of sound waves: The path length difference, Δr, in case of interference between two traveling waves, is related to the phase difference, $\Delta\varphi$, by the relation:

$$\Delta r = |r_2 - r_1| = \lambda\,\frac{\Delta\varphi}{2\pi}$$

in phase (fully constructive)	out of phase (fully distructive)
$\Delta r = \pm n\,\frac{\lambda}{2}$, n is even	$\Delta r = \pm n\,\frac{\lambda}{2}$, n is odd

➔ A listener hears two sound waves from two loud-speakers, with the same frequency of 85 Hz that are in phase. At the listener's location a phase difference of 450º is detected. What is the path difference if the speed of the waves is 340 m/s.

✓
$$\Delta r = \lambda\,\frac{\Delta\varphi}{2\pi} = \left(\frac{340}{85}\right)\left(\frac{450\times\frac{\pi}{180}}{2\pi}\right) = \underline{5 \text{ m}}.$$

➔ A sound wave of wavelength λ = 50.0 cm enters the tube shown in figure (1) at the source end. What must be the smallest radius "r", other than zero, such that a maximum sound will be heard at the detector end?

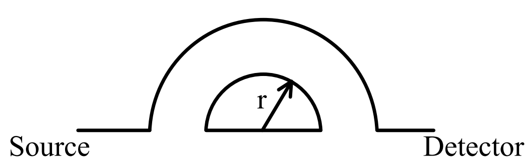


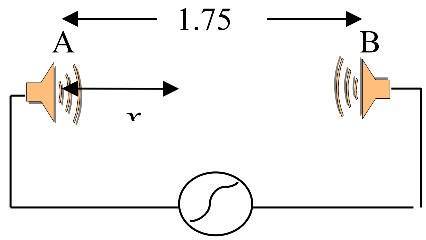
Figure (1)

✓ In this case, use $n = 2$ in the fully constructive interference $\Delta L = n\dfrac{\lambda}{2} = \lambda$, we can get:

$$\Delta L = \frac{2\pi r}{2} - 2r = (\pi - 2)r = \lambda \quad \Rightarrow \quad r = \frac{\lambda}{\pi - 2} = \underline{0.44 \text{ m}}.$$

Homework: What must be the smallest radius "r", other than zero, such that a minimum will be detected at the detector end?

➔ Two speakers, A and B, are driven by a common oscillator at 700 Hz and face each other at a distance of 1.75 m Locate the points along a line joining the two speakers. Where relative minima (nodes) would be expected. [Use: v = 350 m/s]



✓ Suppose that the distance x from the speaker A, then

$$r_1 = x, \quad r_2 = 1.75 - x$$
$$\Rightarrow \quad \Delta r = r_2 - r_1 = 1.75 - 2x$$

For the minimum, equate $\Delta r = \pm n\dfrac{\lambda}{2}, \quad n$ is odd, where $\lambda = \dfrac{350}{700} = \underline{0.5 \text{ m}}$, then solving for x,

one can find: $x = \dfrac{1.75 - 0.25n}{2}$

So, there are 6 minima between the two speakers. Neglect the minima at the speakers position

n	x	$r_2 = 1.75 - x$
-7	1.75	0.0
-5	1.5	0.25
-3	1.25	0. 5
-1	1.00	0.75
1	0.75	1.00
3	0.5	1.25
5	0.25	1.50
7	0	1.75

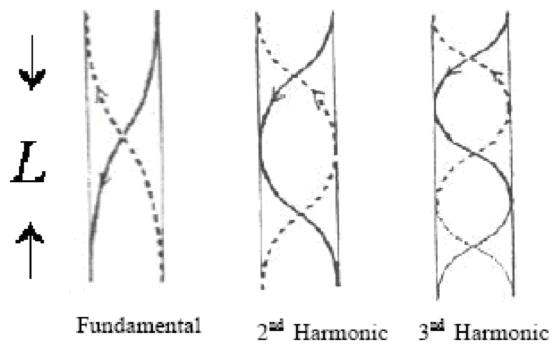
Resonances in air columns: Standing waves are examples for longitudinal waves where nodes are formed at the closed ends and antinodes at open ends (always). Resonance means reinforcement of sound; by means, when the frequency of the vibrating source is equal to the frequency of the vibrations of the air column. In case of resonance, the relation between the frequency (f_n), speed of sound (v), and the length of the tube (L) is defined by:

$$f_n = \begin{cases} nf_1, \quad f_1 = \dfrac{v}{2L}, & n = 1, 2, 3, \cdots \text{(for open-open tube)} \\ nf_1, \quad f_1 = \dfrac{v}{4L}, & n = 1, 3, 5, \cdots \text{(for open-closed tube)} \end{cases}$$

n takes the values: 1 for the fundamental (first harmonic) , 2, for the second harmonic, 3 for the third harmonic, etc.

Notice that:

1- In an open-open tube, all the harmonics are allowed and the number of nodes is less than the number of antinodes.



$$n = 1 \qquad\qquad n = 2 \qquad\qquad n = 3$$

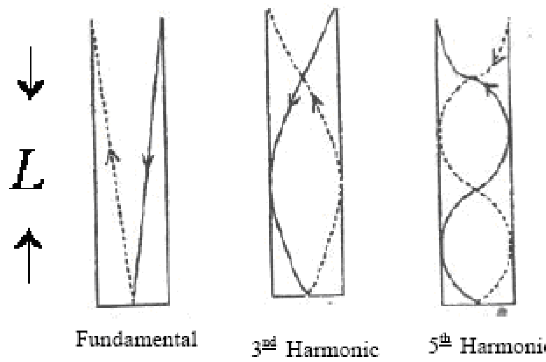
$$L = \frac{1}{2}\lambda_1 \qquad\qquad L = \frac{2}{2}\lambda_2 \qquad\qquad L = \frac{3}{2}\lambda_3$$

$$\lambda_1 = 2L \qquad\qquad \lambda_2 = \frac{2}{2}L \qquad\qquad \lambda_3 = \frac{2}{3}L$$

$$f_1 = \frac{1}{2L}v \qquad\qquad f_2 = \frac{2}{2L}v \qquad\qquad f_3 = \frac{3}{2L}v$$

$$\Rightarrow \quad f_n = \frac{n}{2L}v, \qquad n = 1, 2, 3\cdots$$

2- In an open-closed tube, only the odd harmonics are allowed and the number of nodes is equal to the number of antinodes.



$n=1$	$n=3$	$n=5$
$L=\frac{1}{4}\lambda_1$	$L=\frac{3}{2}\lambda_3$	$L=\frac{5}{2}\lambda_5$
$\lambda_1=4L$	$\lambda_3=\frac{4}{3}L$	$\lambda_5=\frac{4}{5}L$
$f_1=\frac{1}{4L}v$	$f_3=\frac{3}{4L}v$	$f_5=\frac{5}{4L}v$

$$\Rightarrow \quad f_n=\frac{n}{4L}v, \qquad n=1,3,5\cdots$$

➔ An air column 2 m in length is open at both ends. The frequency of a certain harmonic is 410 Hz, and the frequency of the next higher harmonic is 492 Hz. Determine the speed of sound in the air column.

✓ Suppose that

$$f_n = nf_1 = 410 \text{ Hz}, \qquad \text{and} \qquad f_{n+1} = (n+1)f_1 = 492 \text{ Hz}$$

By subtraction one gets:

$$f_1 = f_{n+1} - f_n = 82 \text{ Hz},$$

and this gives:

$$v = 2L(f_1) = 2\times 2\times 82 = \underline{328 \text{ m/s}}.$$

also

$$n = \frac{f_n}{f_1} = \frac{410}{82} = \underline{5}.$$

➔ If two adjacent natural frequencies of an organ pipe (open at one end) are determined to be is 550 Hz and 650 Hz, calculate the fundamental frequency and the length of this pipe. (Speed of sound in air 340 m/s)

✓ Assuming that the resonances occur at n and $n + 2$, then

$$f_n = nf_1 = 550 \text{ Hz}, \qquad \text{and} \qquad f_{n+2} = (n+2)f_1 = 650 \text{ Hz}$$

Dividing the two equations one gets:

$$\frac{n}{n+2}=\frac{550}{650} \quad \Rightarrow \quad n=\underline{11}$$

So, the fundamental frequency is

$$f_1 = 550/11 = \underline{50\text{ Hz}}.$$

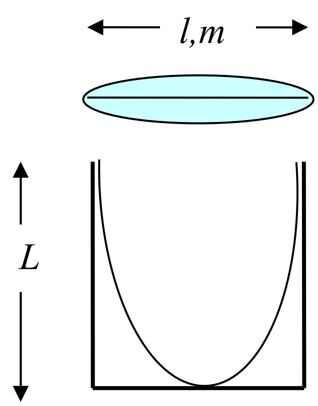
To calculate the length, we know that the resonance in a tube open at one end, the frequency is given by the relation

$$f_n=(n)\frac{v}{4L} \quad \Rightarrow \quad L=\frac{340}{4\times f_1}=\frac{340}{4\times 50}=\underline{1.7\text{ m}}.$$

and the wavelength is:

$$\lambda = 4L = \underline{6.8\text{ m}}.$$

➔ A tube of length L = 1.5 m is closed at one end. A stretched wire is placed near the open end, see figure. The wire has a length l = 0.25 m and mass of m = 7.5 g. It is fixed at both ends and vibrates in its fundamental mode. By resonance, it sets the air column in the tube into oscillation at that column's fundamental frequency. Find the tension in the wire. [Speed of sound in air v_o = 340 m/s.]



✓ For the wire $f_1=\frac{v}{2l}=\frac{1}{2l}\sqrt{\frac{F}{\mu}}$, and for the tube. $f_1=\frac{v_o}{4L}$. By equating both equations one finds:

$$F=\mu\frac{v_o^2 l^2}{4L^2}=\left(\frac{7.5\times10^{-3}}{0.25}\right)\frac{(340)^2\times(0.25)^2}{4\times(1.5)^2}\approx \underline{24\text{ N}}.$$

Doppler Effect: the relation between the frequency emitted by a source, f_s, and the frequency heard by an observable, f_o, is given by:

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

where v is the speed of sound in air. The subscripts o and s are used to represent the observer and the source respectively. Upper signs are used when the source and the observer move toward (approach) each other. Lower signs are used when the source and the observer move away from each other.

➔ A passenger in an automobile is traveling at 22 m/s toward a stationary siren that is emitting a 220 Hz note. Calculate the frequency that the passenger hears. The speed of sound in air is 345 m/s.

✓ $$f_o = 220\left(\frac{345+22}{345}\right) = \underline{234 \text{ Hz}},$$

➔ A sound wave is incident upon a racing car moving toward the source with speed of 0.25 v, where v is the speed propagation of sound wave. The sound wave frequency measured in the car is 1.0×10^6 Hz. What is the frequency of the source?

✓ $$f_o = f_s\left(\frac{v+0.25v}{v}\right) = 1.0\times10^6 \text{ Hz} \quad \Rightarrow \quad f_s = 0.8\times10^6 \text{ Hz},$$

➔ Standing at a crosswalk, you hear a frequency $f_o(\text{approaching}) = 550$ Hz from a siren on an approaching police car. After the police car pass, the observed frequency of the siren is $f_o(\text{away}) = 410$ Hz. Determine the car's speeds v_s from the observations. (Speed of sound in air = 343 m/s.)

✓ $$f_o(\text{approaching}) = f_s\left(\frac{343}{343-v_s}\right) = 550,$$
$$f_o(\text{away}) = f_s\left(\frac{343}{343+v_s}\right) = 410,$$

then

$$\frac{550}{410} = \left(\frac{343+v_s}{343-v_s}\right) \quad \Rightarrow \quad v_s = \underline{50\text{ m/s}}.$$

➔ A police car moving at 20 m/s with its horn blowing, at frequency of f_s =1200 Hz, is chasing another car going at 16 m/s. What is the apparent frequency of the horn as heard by the driver being chased? Take the speed of sound in air to be 340 m/s.

✓ $$f_o\,(\text{chasing car}) = 1200\left(\frac{340-16}{340-20}\right) = \underline{1215\text{ Hz}}.$$

➔ Two cars are heading straight at each other with the same speed v_c. The horn of one, with frequency $f_s = 3000$ Hz, is blowing, and is heard to have a frequency of 3300 Hz by the people in the other car. Find v_c if the speed of sound is 340 m/s.

✓ $$3300 = 3000\left(\frac{340+v_c}{340-v_c}\right) \quad \Rightarrow \quad v_c = \underline{16.2\text{ m/s}}.$$

➔ The whistle on a train generates a tone of 440 Hz as the train approaches a station at 30 m/s. (assume the speed of sound in air = 331 m/s.)

(a) Find the frequency that a stationary observer standing at the station will hear.

✓ $$f_o = 440\left(\frac{331+0}{331-30}\right) = 484\text{ Hz},$$

(b) Suppose a wind blows at 20 m/s in the same direction as the motion of the train. What is the frequency that a stationary observer standing at the station will hear?

✓ $$f_o = 440\left(\frac{331+20}{331+20-30}\right) = 481\text{ Hz},$$

➔ To determine the speed of a moving car v_c, a sound of frequency f_s = 500 Hz is sent from a stationary police car. The sound is reflected back the car and detected by the police car with a new frequency f'_s = 600 Hz.

(a) Write down an expression for the frequency f_c detected by the driver of the car.

✓ $$f_c = f_s\left(\frac{v+v_c}{v}\right)$$

(c) Calculate the speed of the car. (Speed of sound in air v = 333 m/s).

$$f\,'_s = f_c\left(\frac{v}{v-v_c}\right) = f_s\left(\frac{v+v_c}{v-v_c}\right)$$

✓

$$\Rightarrow \quad \frac{600}{500} = \left(\frac{333+v_c}{333-v_c}\right) \quad \Rightarrow \quad v_c = \underline{30.3\text{ m/s}}.$$

(c) If the speed limit is 90 km/h, does the driver of the car deserve a speed ticket?

✓ $$v_c = 30.3\text{ m/s} = \underline{109\text{ km/hours}}$$

The driver deserves a speed ticket.

True and False Statements

1. Mechanical waves need a medium to propagate. **T**
2. Sound is a form of energy. **T**
3. Sound waves are transverse waves. **F**
4. Sound is a longitudinal wave produced by vibrating source. **T**
5. Sound needs a medium to propagate through. **T**
6. The speed of sound depends on the density of the medium. **T**
7. The speed of sound increases with increasing the temperature the medium. **T**
8. Sound travels in air as concentric waves of compression and rarefaction. **T**
9. A sound wave travels from air to water, then its speed increases. **T**
10. A sound wave travels from air to water, then its frequency decreases. **F**
11. For a tube closed at one end, only odd harmonics are present. **T**
12. For a tube open at both ends, only odd harmonics are present. **F**
13. For a tube open at both ends, number of nodes = number of antinodes. **F**
14. For a tube closed at one end, number of nodes < number of antinodes. **F**
15. The speed of sound increases with increasing the temperature of. **T**
16. The formula $f_n = \frac{nv}{4L}$, $(n = 1,3,\ldots)$ is used for a tube open at both ends. **F**

Supplementary Problems

- When a sound wave travels from air into steel,

(a) it changes from a longitudinal wave into transverse wave.
(b) it's velocity decreases.
(c) it's frequency increases.
(d)@ it's wavelength increases.
(e) it becomes more intense.

- A man strikes a long steel rod at one end. Another man, at the other end with his ear close to the rod, hears the sound of the blow twice (one through air and once through the rod), with a 0.1 seconds interval between. How long is the rod? [For the steel, the bulk modulus = 2.1 10^{11} Pa, and the ρ = 7.0 10^3 kg/ m^3. Speed of sound in air = 340 m/s.]

(a) 42 m.
(b) 34 m.
(c)@ 36 m.
(d) 40 m.
(e) 44 m.

- Sound waves

(a) are matter waves.
(b) travel at the same speed in all media.
(c)@ are mechanical waves.
(d) are transverse waves.
(e) are electromagnetic waves.

- Sound waves are not:

(a) pressure waves.
(b) mechanical waves.
(c) compression waves.
(d)@ transverse waves.
(e) longitudinal waves.

- In the figure, the two observers at A and B are hearing the sound emitted by the point source S. What is the time difference between hearing the sound at the two locations? Use 345 m/s as the speed of sound.

(a) 3.17 s

(b) 0.053 s
(c)@ 0.315 s
(d) 0.368 s
(e) 1.89 s

- The volume of a certain solid shrinks by 2 parts in 10^6 when it is subject to an external hydrostatic pressure of 1 atm. ρ of the solid is 8.0 g/cm^3. What is the speed of a longitudinal wave through this material?

(a) 3.4×10^3 m/s.
(b) 1.5×10^3m/s.
(c) 2.5×10^2 m/s.
(d)@ 2.5×10^3 m/s.
(e) 3.4×10^2 m/s.

- In a liquid having ρ =1.30×10^3 kg/ m^3, longitudinal waves with frequency of 400 Hz are found to have a wavelength of 8.0 m. Calculate the bulk modulus of the liquid.

(a) 6.64×10^{12} Pa.
(b)@ 1.33×10^{10} Pa.
(c) 9.62×10^7 Pa.
(d) 3.12×10^6 Pa.
(e) 1.20×10^{11} Pa.

Hint : $v = \sqrt{\dfrac{B}{\rho}} \Rightarrow B = \rho v^2 = \rho(f\,\lambda)^2$

$B = 1.30\times10^3(400\times8)^2 = \underline{1.33\times10^{10}\text{ Pa}}$

- If two sound waves, one in air and the other in water, are of equal intensity. What is the ratio of the pressure amplitude of the wave in water to that of the wave in air? (ρ (air)= 1.21 kg/m^3, v(air)= 343 m/s, ρ (water)= 1×10^3 kg/m^3, v(water)= 1482 m/s)

(a) 78.2
(b) 35.7
(c) 99.2
(d) 82.3
(e)@ 59.8

- The maximum pressure amplitude that the human ear can tolerate in loud sounds is 28 Pa. What is the displacement amplitude for such a sound in air of $\rho = 1.21$ kg/m^3 at a frequency of 5.0×10^3 Hz? [speed of sound in air = 343 m/s].

(a) 4.15×10^{-6} m.
(b) 50.5×10^{-6} m.
(c) 11.0×10^{-6} m.
(d)@ 2.15×10^{-6} m.
(e) 8.30×10^{-6} m.

- A sinusoidal sound wave is described by the displacement

$$S(x,t) = 2\times10^{-8} \cos[1.25x - 1850t],$$

where x is in meters and t is seconds. What is the pressure amplitude of this wave if it is traveling in a material with a bulk modulus of 2.1×10^9 N/ m^2?

(a)@ 53 Pa
(b) 77 Pa
(c) 66 Pa
(d) 82 Pa
(e) 44 Pa

- Two identical speakers, facing each other are driven by a common oscillator of frequency 600 Hz. A man, at the midpoint between the speakers, starts moving toward one of them. He reaches the first minimum sound when he is 1 m from one of the speakers. Find the distance between the speakers. (Speed of sound = 343 m/s.)

(a) 6.1 m
(b) 4.0 m
(c)@ 2.3 m
(d) 5.6 m
(e) 4.5 m

- Two speakers are driven by a common oscillator and face each other at a distance of 1.500 m. A man is standing at 0.700 m from one of the speakers along the line joining the two speakers. What is the highest frequency of the oscillator, within the audible range (20.0 Hz to 20.0 kHz), so that the man hears a minimum sound? (Speed of sound = 343 m/s).

(a) 19.9 kHz
(b)@ 18.9 kHz
(c) 12.6 kHz
(d) 15.9 kHz
(e) 10.3 kHz

- Two sound waves, from two different sources with the same frequency, 660 Hz, travel at a speed of 330 m/s. The sources are in phase. What is the phase difference of the waves at a point that is 5.0 m from one source and 4.0 m from the other? (The waves are traveling in the same direction.)

(a) 1π .
(b) 2π .
(c)@ 4π .
(d) 3π .
(e) 5π .

➢ A sound wave of 50.0 cm wavelength enters the tube shown in figure(1) at the source end. What must be the smallest radius(r) (other than zero) such that a maximum sound will be heard at the detector end?

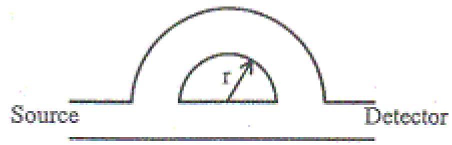
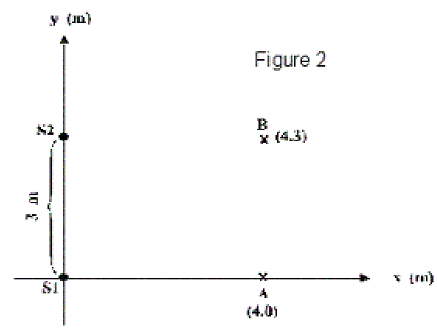


Figure (1)

(a) 15.9 cm.
(b) 21.3 cm.
(c) 33.0 cm.
(d) 17.5 cm.
(e)@ 43.8 cm.

➢ Two point sources S1 and S2 are placed on the y-axis as shown in figure 1. The two sources are in phase and emit identical sound waves with frequency 860 Hz. An observer starts at point A and moves to point B along a straight line parallel to the y-axis. How many points of maximum intensity (constructive interference) will he observe? (speed of sound in air = 344 m/s).



At the mid-point between A and B: $\Delta r = 0 \Rightarrow$ maximum

At the starting point A or B: $\Delta r = 5 - 4 = 1$ m

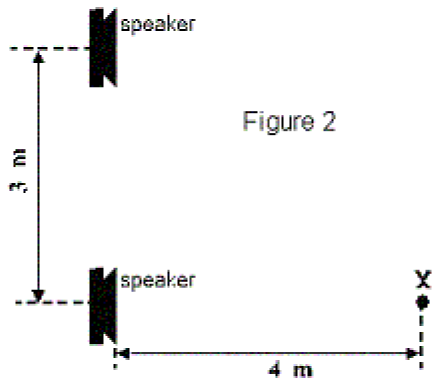
(a) 1
(b) 4
(c) 0
(d)@ 5
(e) 3

Compare with: $\Delta r = \pm n \dfrac{\lambda}{2} = \pm n (\dfrac{v}{2f}) = \pm n \dfrac{344}{2 \times 860} = \pm n \times 0.2$

one finds $n = \pm \dfrac{1}{0.2} \quad = \pm 5$

So, he will statr at A with $(n = -5)$ i.e. minimum, and will go to through the maximum with $n = -4, -2, 0, 2, 4$.

➢ Two small identical speakers are in phase(see figure 2). The speakers are 3.0 m apart. An observer stands at point X, 4.0 m in front of one of the speakers. The sound he hears will be a maximum if the wavelength is



(a) 2.0 m.
(b) 3.0 m.
(c) 1.5 m.
(d)@ 1.0 m.
(e) 2.5 m.

- Two speakers face each other and emit sound waves in air with a frequency of 500 Hz, as shown in figure 1. The phase difference between the sound waves emitted by the two speakers at point A is 2.35 radians. What is the distance between A and S_2 ? The speed of sound in air is 343 m/s.

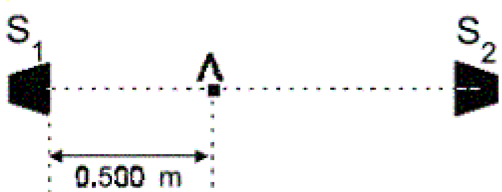


FIGURE 1

(a) 0.256 m
(b) 1.05 m
(c) 3.17 m
(d)@ 0.756 m
(e) 0.500 m

- Two identical speakers A and B are driven by a common oscillator at 256 Hz and face each other at a distance of 10.0 m (see figure 2). A small detector is located midway between the two speakers (at point O). Find the distance that the detector has to move towards A along the line joining A and B to detect the first minimum in the sound intensity. [speed of sound in air = 343 m/s].

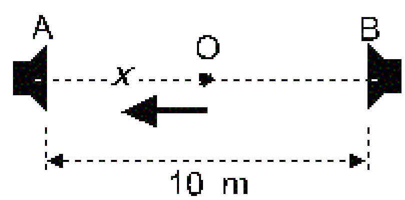


Figure 2

(a) 0.670 m
(b) 0.172 m

Consider r is the distance from foint O and x, then

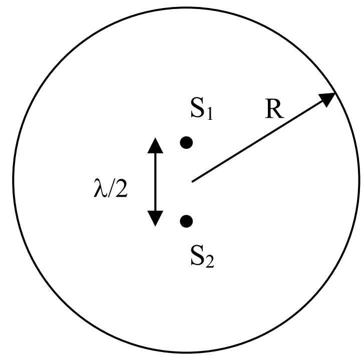
At point x: $\Delta r = (0.5 + r) - (0.5 - r) = 2r$

First minima will be at: $\Delta r = \frac{\lambda}{2} = \frac{v}{2f} = \frac{344}{2 \times 256} = 0.67$ m

$r = \frac{0.67}{2} = \underline{0.335\ \text{m}}$.

(c)@ 0.335 m
(d) 1.00 m
(e) 0.195 m

- Two transmitters, S_1 and S_2 shown in the figure, emit identical sound waves of wavelength λ. The transmitters are separated by a distance $\lambda/2$. Consider a big circle of radius R with its center halfway between these transmitters. How many interference maxima are there on this big circle?

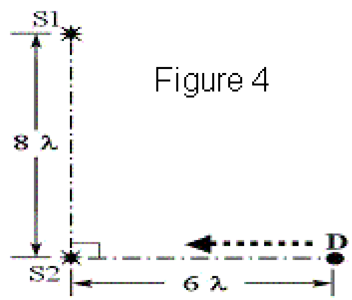


(a)@ 2.
(b) 5.
(c) 1.
(d) 6.
(e) 8.

- A listener hears two sound waves from two loud-speakers that are in phase. At the listeners location a phase difference of 450º is detected. What is the path difference if the wavelength of the waves is 4 m.

(a) 10 m.
(b)@ 5 m.
(c) 99 m.
(d) 1 m.
(e) zero.

- Two loudspeakers, S_1 and S_2, emit sound waves of identical wavelength and amplitude. They are situated as shown in figure 4. The two speakers are in phase. A listener starts to walk from point D toward S_2 along a line perpendicular to the line joining S_1 and S_2. How many times will he hear a minimum in sound intensity as he moves from D to S_2?



(a) 5
(b) 2
(c) 1
(d)@ 4
(e) 3

- In figure 4, two small identical speakers are connected (in phase) to the same source. The speakers are 4.10 m apart and at ear level. An observer stands at X, 8.00 m in front of one speaker. In the frequency range 200 Hz-500 Hz, the sound he hears will be most intense if the frequency is: [speed of sound in air is 343 m/s]

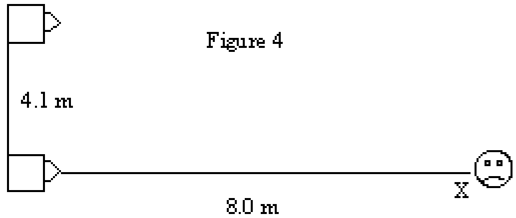


Figure 4

(a) 600 Hz.
(b)@ 346 Hz.
(c) 500 Hz.
(d) 210 Hz.
(e) 422 Hz.

- In figure 1, two speakers, A and B, are driven by the same oscillator at a frequency of 170 Hz and face each other at a distance of 2.0 m. What is the number of minima along the line joining the two sources? [Consider only the nodes between the two sources.] [Take the speed of sound in air = 340 m/s]

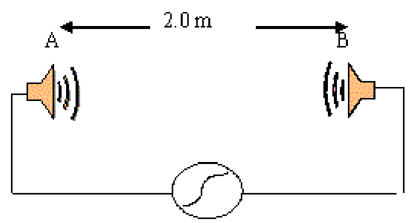


Figure 1

(a)@ 2
(b) 4
(c) 1
(d) 5
(e) zero

- Two equal waves, of wavelength 4 m and amplitude A, are produced by two sources S1 and S2 as shown in figure 1. S_1 is at a distance of 3 m from point P and S_2 is at a distance of 5 m from P. When the sources are operated in phase, what is the amplitude of oscillation at P?

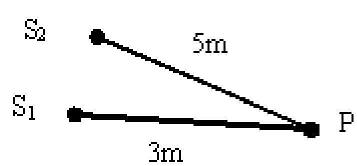


Figure 1

Using: $\Delta r = S_2P - S_1P = 2$ m, (1)

Also: $\Delta r = n\dfrac{\lambda}{2} = n(4)$ (2)

from (1) and (2), one finds $n = 1$

$\Rightarrow$ fully destructive

$\Rightarrow$ <u>Amplitude = 0</u>

(a) 3A/2.
(b)@ zero.
(c) A/2.
(d) 2A.
(e) A.

A tone has a frequency of 1800 Hz and intensity level of 110 dB in air. What is the amplitude of oscillation of air molecules. [ρ of air = 1.21 kg/m^3, speed of sound in air = 343 m/s].

(a) 3.54×10^{-8} m.
(b) 1.81×10^{-10} m.
(c) 2.03×10^{-12} m.
(d) 2.57×10^{-16} m.
(e)@ 1.94×10^{-6} m.

- The intensity of sound waves at 5 m from a speaker vibrating at 1000 Hz is 0.5 W/ m^2. Determine the displacement amplitude of the particles in the wave at that location (5 m away from the speaker). (ρ of air = 1.3 kg/m^3 and the speed of sound in air = 340 m/s).

(a) 2.3×10^{-7} m
(b) 1.2×10^{-5} m
(c) 6.5×10^{-6} m
(d)@ 7.6×10^{-6} m
(e) 9.5×10^{-7} m

A source of sound (1000 Hz) emits uniformly in all directions. An observer 3.0 m from the source measures a sound level of 40 dB. Calculate the average power output of the source.

(a) 2.87×10^{-6} W
(b) 0.34×10^{-6} W
(c) 10.5×10^{-6} W
(d) 5.23×10^{-6} W
(e)@ 1.13×10^{-6} W

Consider two sound waves “A” and “B” propagating in the same medium. Find the ratio of the intensity of the sound wave “A” to the intensity of the sound wave “B” if the sound level of wave “A” is 20 dB greater than the sound level of wave B.

(a) 20
(b) 15
(c) 5
(d) 10
(e)@ 100

A certain sound level is increased by 30 dB. By what factor is the intensity increased?

(a) 900
(b) 2700
(c) 300
(d)@ 1000
(e) 30

- Determine the intensity of a harmonic longitudinal wave with pressure amplitude of 8.0×10^{-3} N/ m^2 propagating inside a tube filled with helium. (For helium: ρ = 0.179 kg/ m^3 and speed of sound waves = 972 m/s.).

(a)@ 1.8×10^{-7} W/ m^2.
(b) 9.2×10^{-8} W/ m^2.
(c) 1.5×10^{-6} W/ m^2.
(d) 3.7×10^{-7} W/ m^2.
(e) 4.6×10^{-8} W/ m^2.

- A group of students, in a class room, produce a sound level of 53 dB. A single students speaking normally produces a sound level of 40 dB. How many students are in the room? (Assume each student in the group speaks at the same level as did the single person.)

(a) 13.
(b)@ 20.
(c) 30.
(d) 10.
(e) 5.

- If the distance from a source of sound increases by 1 meter, the sound level is decreased by 2 dB. Assume the loudspeaker that is emitting this sound emits sound in all directions. The original distance from the sound source is:

(a) 12.0 m.
(b)@ 3.86 m.
(c) 7.72 m.
(d) 1.93 m.
(e) 9.93 m.

- A 1.5×10^{-6} W point source emits sound waves isotropically. What is the sound level 2.5 m from the source?

(a) 30 dB.
(b) 55 dB.
(c) 39 dB.
(d)@ 43 dB.
(e) 16 dB.

- Find the ratio of the intensities of two sound waves if the difference in their intensity levels is 7 dB.

(a) 3.
(b) 7.
(c)@ 5.
(d) 1.
(e) 9.

- A sound source located at the origin emits sound with an average power of 0.04 W. Two detectors are located on the positive x-axis. Detector A is at x = 3.0 m and detector B is at 5.0 m. What is the difference in sound level between A and B?

(a) 2.2 dB
(b) 3.3 dB
(c)@ 4.4 dB
(d) 5.5 dB
(e) 1.1 dB

- You are standing at a distance D from a point source of sound wave. You walk 30.0 m toward the source and observe that the intensity of these waves has doubled. Calculate the distance D.

(a) 15 m.
(b)@ 102 m.
(c) 493 m.
(d) 232 m.
(e) 300 m.

- Which of the following statements is CORRECT?

(a) The power transmitted by a sinusoidal wave on a string decreases with increasing frequency of the wave.
(b) The speed of sound is the same in all media.
(c) Sound waves can travel in vacuum.
(d) The power intercepted by a sound detector does not depend on the area of the detector.

(e)@ Electromagnetic waves can travel in vacuum.

- A point source of a sound wave has a power of 0.50 W. At what distance from the source will the sound level be 90 dB?

(a) 34 m
(b) 8.9 m
(c) 80 m
(d)@ 6.3 m
(e) 40 m

- The intensity of sound wave A is 100 times that of sound wave B. What is the difference between their sound levels?

(a)@ 20 dB
(b) 10 dB
(c) 2 dB
(d) 100 dB
(e) 3 dB

- If an observers distance from a point source is doubled, the sound intensity level will be:

(a) increased by 6 dB.
(b) decreased by 4 dB.
(c)@ decreased by 6 dB.
(d) decreased by 36 dB.
(e) increased by 36 dB.

- Two waves are given by the equations:

$$y_1(x,t) = 5.0 \sin(0.25\, x + 75\, t)$$
$$y_2(x,t) = 10.0 \sin(0.50\, x + 150\, t)$$

in SI units. The intensity ratio of I1/I2 of the two waves is:

(a)@ 1/16.
(b) 1/2.
(c) 1/3.
(d) 4.
(e) 1/4.

- The ratio of the intensities of two sound waves is 5. Find the difference in their intensity levels.

(a) 1 dB.
(b) 4 dB.
(c)@ 7 dB.
(d) 6 dB.

(e) 2 dB.

- A person closes his windows to reduce the street noise from 10^{-4} W/ m^2 to 10^{-8} W/ m^2. What is the change in the intensity level in dB?

(a) - 60.
(b) - 20.
(c)@ - 40.
(d) 40.
(e) 20.

$$\text{Ans}: \beta_2 - \beta_1 = 10\ln(\frac{I_2}{I_1}) = 10\ln(\frac{10^{-8}}{10^{-4}})$$
$$= \underline{-40}$$

- A point source emits 30 W of sound. A small microphone has an area of 0.75 cm^2 is placed 10 m from the point source. What power does the microphone receive?

(a) 30×10^{-6} W.
(b) 0.1×10^{-6} W.
(c) 9.3×10^{-6} W.
(d)@ 1.8×10^{-6} W.
(e) 3.6×10^{-6} W.

- At a distance of 5.0 m from a point source, the sound level is 110 dB. At what distance is the sound level 95 dB?

(a) 7.1 m
(b) 5.0 m
(c) 14 m
(d)@ 28 m
(e) 42 m

$$\text{Ans}: \beta_2 - \beta_1 = 10\ln(\frac{I_2}{I_1}) = 20\ln(\frac{r_1}{r_2})$$
$$\Rightarrow r_2 = r_1 \times 10^{-(\beta_2-\beta_1)/20} = 5.0\times10^{-(95-110)/20} = \underline{28 \text{ m}}$$

- A point source emits sound isotropically. At a distance of 3.00 m from the source, the sound level is 90.0 dB. What is the average power of the source?

(a) 12.6 mW
(b) 56.5 mW
(c) 28.3 mW
(d)@ 113 mW
(e) 315 mW

- The intensity of sound wave A is 800 times that of sound wave B at a fixed point from both sources. If the sound level of sound A is 110 dB, what is the sound level of wave B?

(a) 690 dB.
(b) 555 dB.
(c) 7.3 dB.
(d) 50 dB.
(e)@ 81 dB.

- The intensity level of sound from 10 persons each of intensity level 60 dB is:

(a) 12 dB.
(b) 120 dB.
(c) 600 dB.
(d)@ 70 dB.
(e) 300 dB.

- A person is hearing a sound level of 70 dB at a distance of 3.0 m from a point source. Assuming that the sound is emitted isotropically, find the power of the source.

(a) 8.6×10^{-3} W.
(b) 2.3×10^{-7} W.
(c) 2.9×10^{-4} W.
(d)@ 1.1×10^{-3} W.
(e) 7.7×10^{-3} W.

Hint: $I = I_o 10^{\beta/10} = 10^{-12}10^{7} = 10^{-5}\,\frac{\text{W}}{\text{m}^2}$

$P = 4\pi(3)^2 \times 10^{-5} = \underline{1.1\times10^{-3}\ \text{W}}$

- An air column 2 m in length is open at both ends. The frequency of a certain harmonic is 410 Hz, and the frequency of the next higher harmonic is 492 Hz. Determine the speed of sound in the air column.

(a) 317 m/s.
(b) 320 m/s.
(c)@ 328 m/s.
(d) 342 m/s.
(e) 305 m/s.

- An air column 2 m in length is open at one end and closed at the other end. The frequency of a certain harmonic is 369 Hz, and the frequency of the next higher harmonic is 451 Hz. Determine the speed of sound in the air column.

(a)@ 328 m/s.
(b) 342 m/s.
(c) 325 m/s.
(d) 323 m/s.
(e) 320 m/s.

- The second harmonic of a string, fixed at both ends, of length 0.6 m and linear density 1.1×10^{-3} kg/m, has the same frequency as the fifth harmonic (n=5) of a pipe closed at one end of length 1.0 m. Find the tension in the string. (Speed of sound = 343 m/s).

(a) 90 N
(b) 88 N
(c) 60 N
(d)@ 73 N
(e) 18 N

- During a time equal to the period of a certain vibrating fork, the emitted sound wave travels a distance:

(a) proportional to the frequency of the wave.
(b)@ of one wavelength.
(c) of about 331 meters.
(d) directly proportional to the frequency of the fork.
(e) equal to the length of the fork.

- If two successive frequencies of a pipe, closed at one end and filled by air, are 500 Hz and 700 Hz, the length of the pipe is: [speed of sound in air = 340 m/s].

(a)@ 0.85 m.
(b) 3.40 m.
(c) 1.70 m.
(d) 0.43 m.
(e) 0.18 m.

- Which of the following statements are CORRECT:
  1. Waves carry energy and momentum.
  2. Mechanical waves need a medium to propagate.
  3. Sound waves are transverse waves.
  4. A Wave on a stretched string is a longitudinal wave.
  5. For a tube closed at one end, only odd harmonics are present.

(a) 3 and 5.
(b) 2 and 4.
(c) 1, 2 and 3.
(d)@ 1, 2, and 5.
(e) 1 and 4.

- A 1024 Hz tuning fork is used to obtain a series of resonance levels in a gas column of variable length, with one end closed and the other open. The length of the column changes by 20 cm from one resonance to the next resonance. From this data, the speed of sound in this gas is:

(a) 20 m/s.
(b) 102 m/s.
(c) 51 m/s.
(d)@ 410 m/s.
(e) 205 m/s.

A tube 1.5 m long is closed at one end. A stretched wire i