Name: ______________________________________ Class: __________ Date: _____________

Sec 4 Physics (IP / SSMT)

Topic 16: Sound

I can…	*By the end of this topic, you should be able to:*
☐	relate the loudness and intensity of a sound wave to the square of its amplitude
☐	relate the pitch of a sound wave to its frequency
☐	define ultrasound and give one use of ultrasound
☐	know that a medium is required in order to transmit sound waves and the speed of sound is fastest in solids, then liquids and then air.
☐	describe the production of sound by vibrating sources
☐	describe the longitudinal nature of sound waves in terms of processes of compression and rarefaction
☐	describe how the speed of sound can be determined using reflection of sound waves
☐	describe how the reflection of sound may produce an echo use it for measuring distances
☐	**describe and explain the Doppler Effect and apply the concept in new situations*

Basics of Sound

16.1 SOUND PRODUCTION

A sound wave is produced by a vibrating / oscillating source placed in an elastic medium. The medium can be any solid, liquid or gas. Usually, it is air.

Questions:

(a) What is the significance of the statement "Usually, it is air."?
(b) What is it meant by an elastic medium? Which of the following media are elastic; mud, steel, air, or water?

(a) For human beings, the best medium for hearing sound is air.
(b) Do not mistake elasticity for "stretchiness". It simply means the tendency of the particles in the medium to return to their original positions.

In humans, our voice production process can be simplified as follows. The diaphragm pushes air from the lungs through the vocal folds in the larynx, the air pressure sets the elastic vocal folds into vibration. This process is called voicing. A periodic train of air pulses is thus produced which moves up the vocal pipe.

Hence, the vibrating vocal folds act as the source of the sound waves produced.

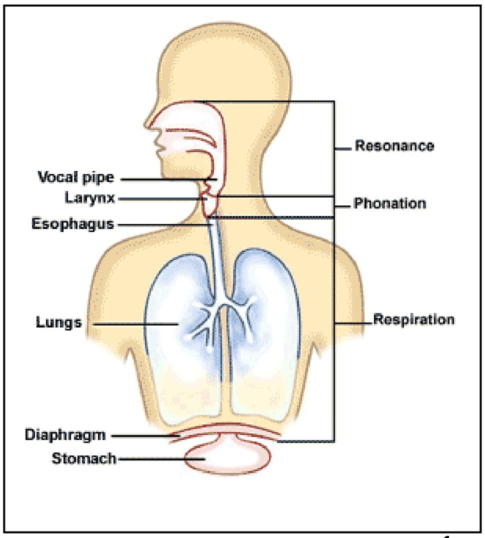
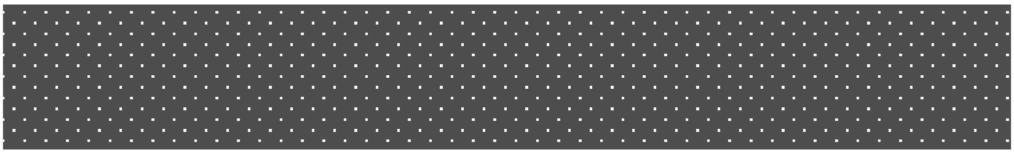


Image retrieved from http://www.singintune.org/voice-production.html

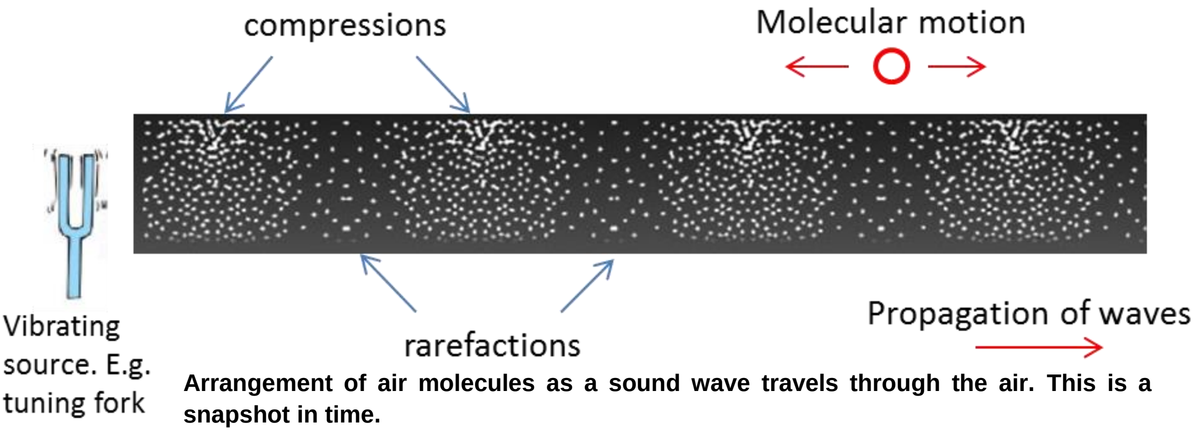
16.2 SOUND TRANSMISSION IN AIR

Sound is a type of **mechanical wave**. This means that a sound wave can only propagate through a medium. Sound cannot travel through a vacuum.

Sound wave in air is an example of a **longitudinal wave**. This means that energy in a sound wave travels in a direction parallel to the direction of vibration of the particles in the medium.



Undisturbed air molecules. If we zoom in more closely, we will observe the molecules to be in constant random motion, in agreement with the Kinetic Model of Matter.

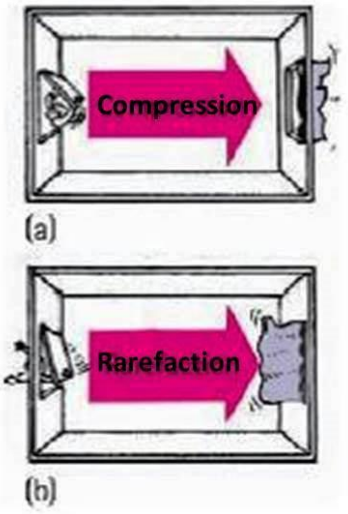


Arrangement of air molecules as a sound wave travels through the air. This is a snapshot in time.

Check you understanding

Question: What are compressions and rarefactions?

The picture on the left shows what it means by compressions and rarefactions.

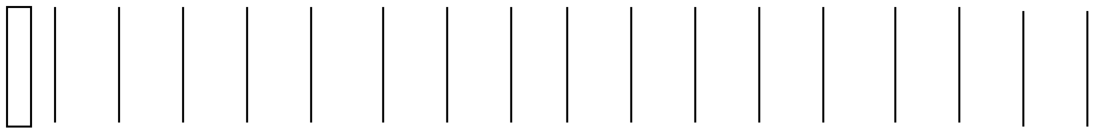


(a) When the door is opened, the door will push the molecules away from their initial positions and into their neighbours. The neighbouring molecules, in turn, push into their neighbours and so on, like a compression travelling along a spring, until the curtain flaps out of the window. A pulse of compressed air has travelled from the door to the curtain. This pulse of compressed air is called a **compression**.

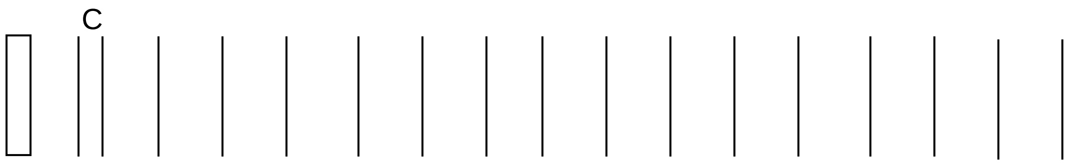
(b) When we close the door, the door pushes some air molecules out of the room. This produces an area of low pressure behind the door. Neighbouring molecules then move into it, leaving a zone of lower pressure behind them. We say this zone of lower-pressured air is *rarefied*. Other molecules farther away from the door, in turn, move into the rarefied regions, and a disturbance again travelled across the room. This is seen by the curtain which flaps inward. This time the disturbance is a **rarefaction**.

Representing sound waves in air

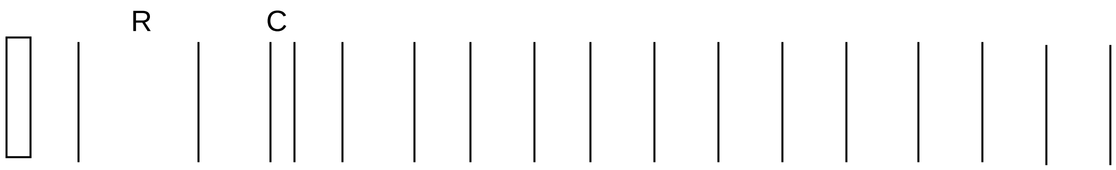
Instead of drawing dots to represent the air molecules, we can also draw lines to represent the air layers.



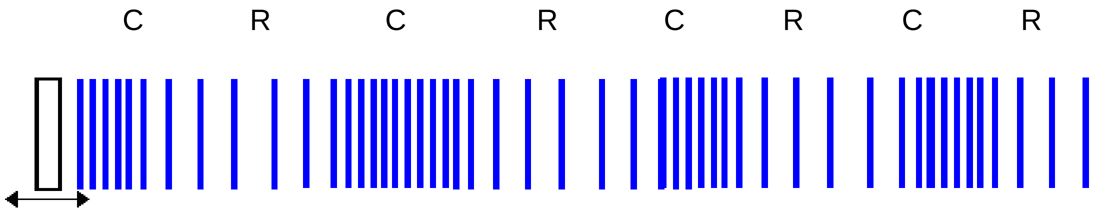
(i) Layers of air in undisturbed positions.



(ii) A compression C is produced as the vibrating source moves rightwards.



(iii) A rarefaction R is produced as the vibrating source moves leftwards.



(iv) After a while, a series of compressions and rarefactions is set up in the air. A straight source of vibration produces plane waves.

16.3 SOUND DETECTION BY HUMAN

The ear lobe receives incoming sound waves and directs them along the canal (about 3cm) towards the ear drum, called the tympanic membrane. The compressions and rarefactions of the longitudinal sound waves cause the ear drum to vibrate. These vibrations are picked up by three bones in the middle ear.

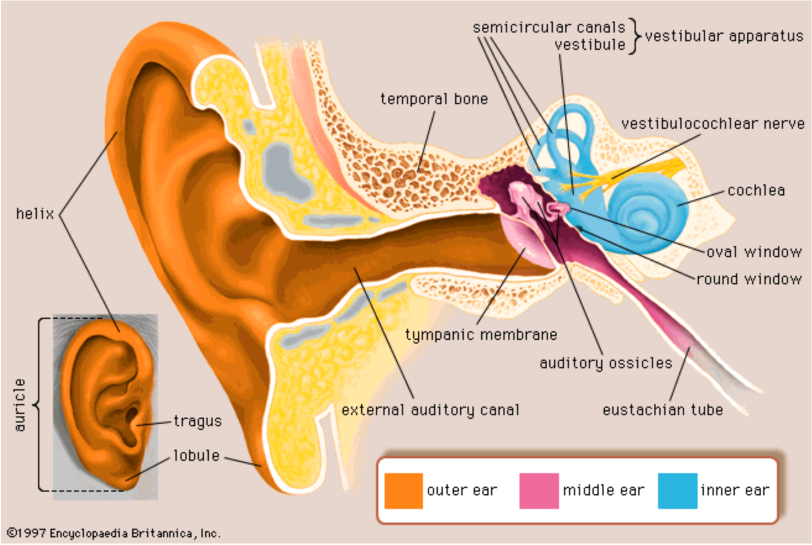
These bones act as a lever system for force and pressure amplifications of about 25 times at the oval window.

Vibrations at the oval window cause pressure waves to be formed in the fluid of the inner ear housing the cochlea tube. Inside the cochlea tube, the pressure waves are picked up by the sensory cells that in turn produce neural impulses that are carried by the auditory nerves to the brain. Hence sound is heard.

The length of the ear canal causes the human ear to be most sensitive to a sound of frequency of 3,000 Hz. The range of audibility of the human ear is between 20Hz to 20,000 Hz. Sound with very low frequencies which are not audible to the human ear is called *infrasound*, while sound with very high frequencies above 20 kHz is called *ultrasound*.

The way the ear works is that sound waves vibrate the eardrum, just inside your ear. That sends waves through a fluid inside a narrow tube called the cochlea, which in turn vibrates tiny hairs which are tuned to the different pitches of the sound. Information from the vibration of the hairs stimulates nerves which send the signals to the brain for processing. The characteristics of sound include pitch and loudness. You can also determine direction and distance from what you hear. Sounds provide information about the environment around you.

The way the ear works is similar to the way a microphone works, where sound vibrates a diaphragm, which causes electrical signals to travel through a wire to a circuit card for processing.



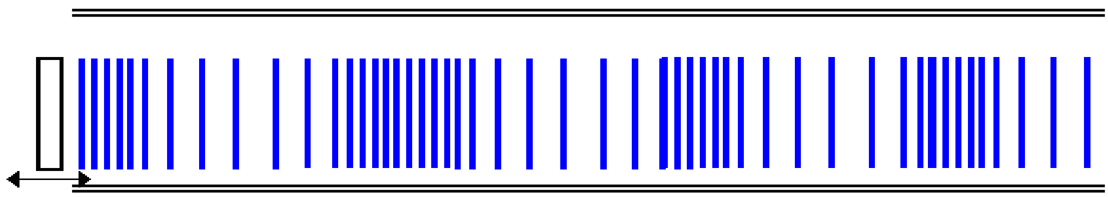
Class Activity: Playing with a sound frequency generator

Using a laboratory function generator, it is possible to generate sounds of various frequencies to test your hearing frequency range. However, if we are not too particular about accuracy and precision, we can use an app on the smart phone to achieve similar effects. Download one and play!

Like the visible spectrum to our eye, there is also an optimum sound frequency range which to our ear is sensitive. Play with the app to find out.

16.4 Representing Sound with Graphs (Longitudinal Wave)

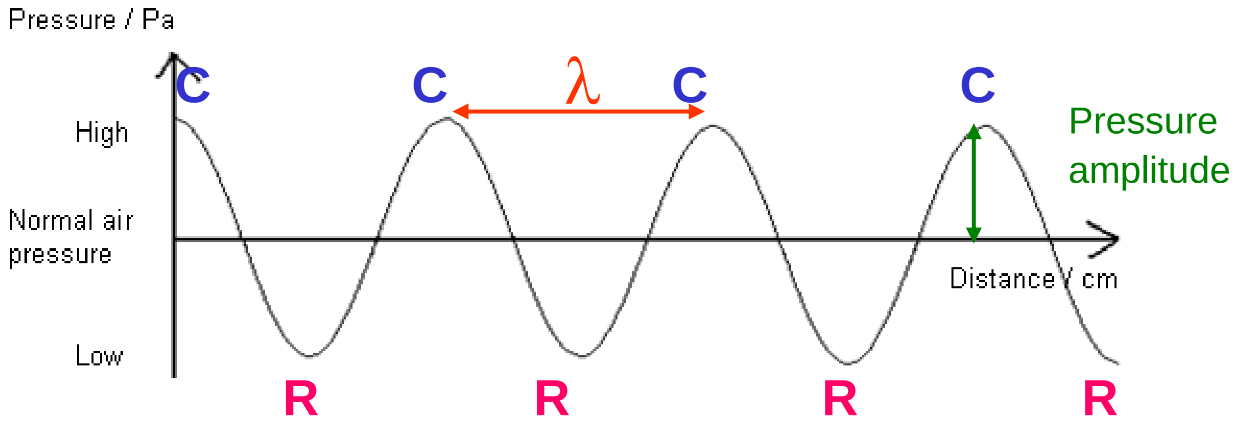
Pressure vs. Distance Graph



Sound waves produced in a hollow pipe of air.

At a compression, the air pressure is higher than the normal air pressure where the air is undisturbed.

At a rarefaction, the air pressure is lower than the normal air pressure.



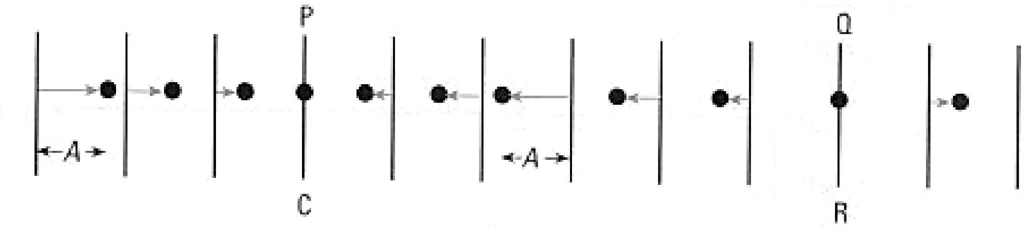
Pressure – distance graph for the sound wave produced in the hollow tube above

Check Your Understanding

On the pressure-distance graph above, label:

1. the regions of compression with C and regions of rarefaction with R.
2. the wavelength and pressure amplitude of the sound wave.

3. The figure below shows the (exaggerated) positions of water molecules at an instant when a sound wave, travelling from left to right, passes through the water. Before the wave arrived, the water molecules were all spaced equally apart as represented by the vertical lines. At the instant shown, particles P and Q are passing through their equilibrium positions.



[Note: measurement may differ based on printed size]

(a) Draw arrows next to each water molecule to indicate the direction of displacement of each molecule from its equilibrium position.

(b) Mark on the figure:

(i) a centre of compression (C), and

(ii) a centre of rarefaction (R).

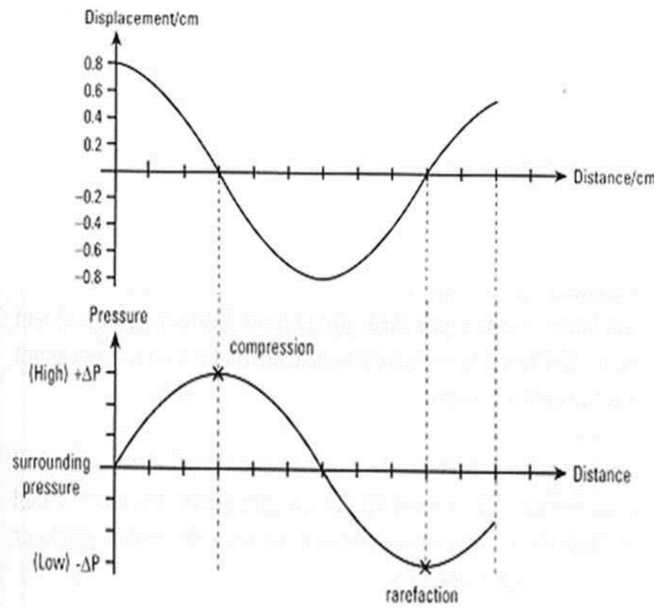
(i) The distance between particles P and Q is half a wavelength.
Wavelength = 2 × distance between particles P and Q
= 2 × 6 cm
= 12 cm
(ii) Amplitude A = 0.8 cm

(c) By making measurements on the figure, find the

(i) wavelength of the wave,

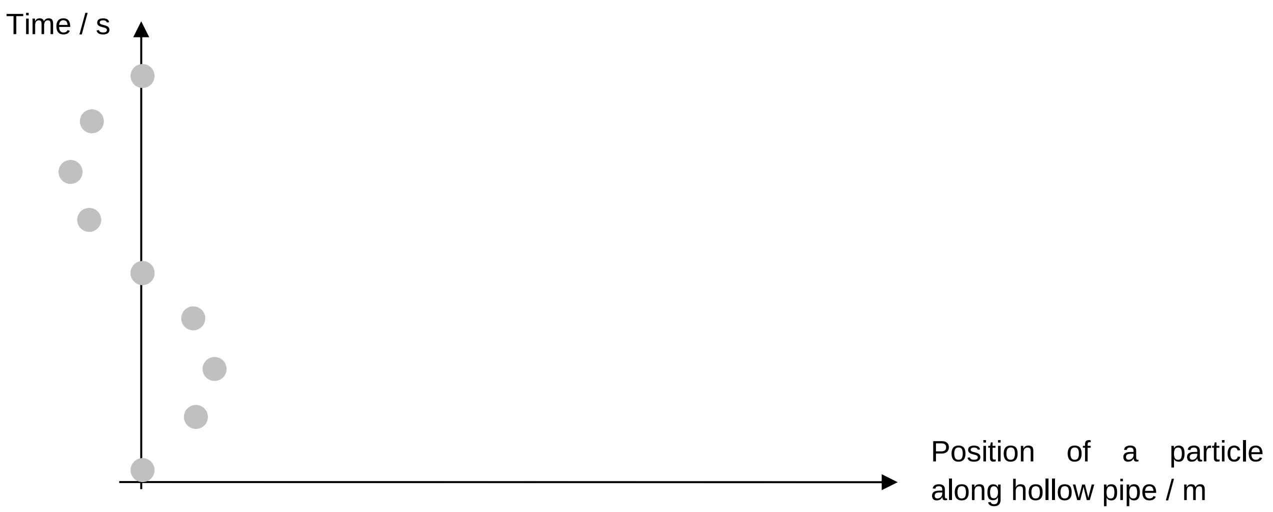
(ii) amplitude of vibration of the water molecules.

(d) For the instant shown in above figure, sketch and label the pressure-distance graph

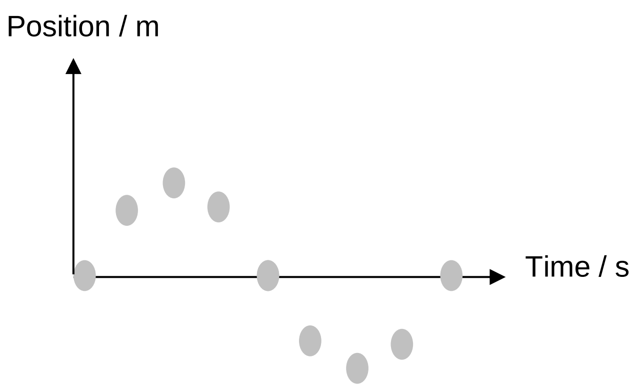


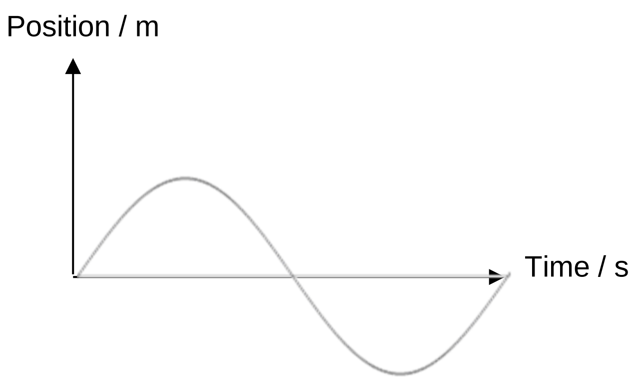
Position vs. Time Graph

If we photograph the motion of a particle in the longitudinal wave described in the previous question, we can obtain its position – time graph. The graph below shows the position of a particle just next to the source along the hollow pipe.



Re-orientating the previous graph so that position becomes the vertical axis, we obtain the following position-time graph for the particle.





16.5 Representing Sound with Equation

Wave speed = wavelength / period

= wavelength x frequency

$$v = \frac{\lambda}{T} = f\,\lambda$$

Any medium which has particles that can vibrate will transmit sound. However, sound waves travel at different speeds in different media.

The table below shows the typical speeds of sound in some media.

Table 16.1 Speeds of sound in some types of solids, liquids and gases.

Material	Speed of sound (m/s)
Gases	
Air (20°C)	344
(25°C)	347
(30°C)	350
Helium (20°C)	999
Hydrogen (20°C)	1330
Liquids	
Liquid helium (4 K)	211
Water (0°C)	1402
Water (100°C)	1543
Mercury (20°C)	1451
Solids	
Polystyrene	1840
Bone	3445
Brass	3480
Pyrex™ glass	5170
Steel	5000
Beryllium	12,870

Based on Table 16.1, sound waves generally travel fastest in solids, followed by liquids and then gases.

The speed of sound in a gas is affected by physical conditions such as wind conditions, temperature and humidity.

Sound travels faster when the gas is at a higher temperature.

Sound also travels faster when humidity is higher. Water vapour in the air increases this speed slightly.

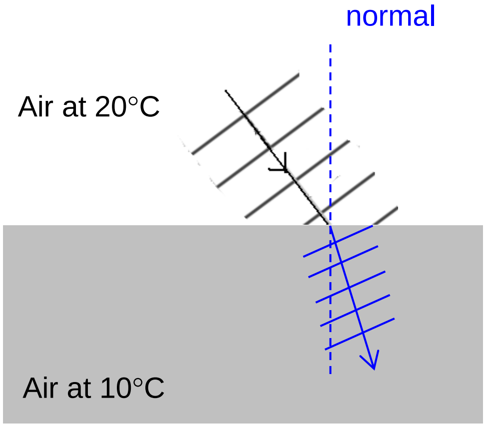
Check Your Understanding

1. Using the Kinetic Model of Matter, explain why sound waves travel fastest in solids and slowest in gases, as shown in Table 16.1.

   The interaction between particles in a solid is the strongest. Particles in a solid have a high tendency to return to their equilibrium position (elastic, not easily deformed) when disturbed. This aids the transfer of energy through oscillations. Hence sound waves travel fastest in solids

   [If particles don't return to their equilibrium position after being disturbed, e.g. fallen dominoes, then no further energy transfer can occur through the medium after the initial pulse has passed through.]

2. From Table 16.1, we see that sound travels faster in warm air than in cold air. Complete the figure below to show what happens to the sound waves (with straight wavefronts) as they travel through two air layers of different temperature. Explain your answer.



Sound waves slow down when they move from air at 20°C to air at 10°C. When the sound waves enter lower temperature air at an angle, they refract / bend towards the normal (line that is perpendicular to a surface)

3. Using the Kinetic Model, explain why it is that sound travel faster in warm air than in cold air.

   Faster moving air molecules in warm air bump into each other more often and therefore can transmit a pulse in less time.

   For every degree rise in temperature above 0^oC, the speed of sound in air increases by 0.6 ms^{-1}.

   It is worth to note that the speed of sound in a gas is about ¾ the average speed of the gas molecules.

16.6 LOUDNESS, PITCH & QUALITY

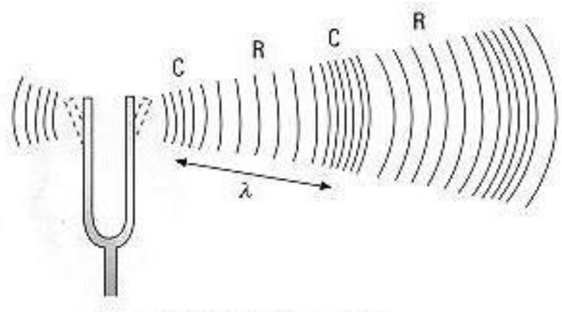
We are surrounded by a great variety of sounds every day. Sounds such as those produced by musical instruments, ipod and television are enjoyable. Sounds such as those produced by construction work and heavy traffic on a busy road are undesirable. The pitch, loudness and quality are characteristics of a sound wave that help us determine if the sound is pleasant or not.

Pitch and Frequency

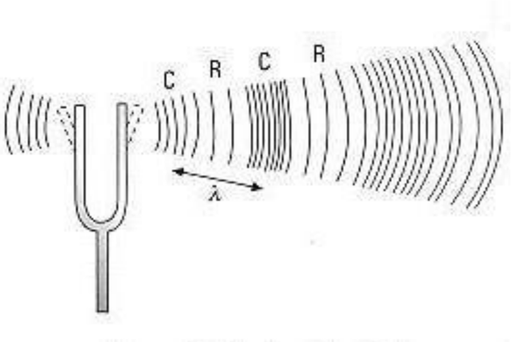
When we describe a musical note or sound as "high" or "low", we are referring to the pitch of the sound. Pitch is relative. For example, a guitar produces notes of lower pitch than a violin. But compared to a cello, a guitar produces notes of higher pitch. The pitch of a musical note is related to the frequency of its sound wave.

Recall: Frequency is a measure of the number of cycles of waves produced in one second.

We can use a tuning fork to produce a note of a certain frequency. The two figures show tuning forks with prongs of different lengths. When set into vibration, both tuning forks will produce sound waves of different frequencies into the surrounding air.

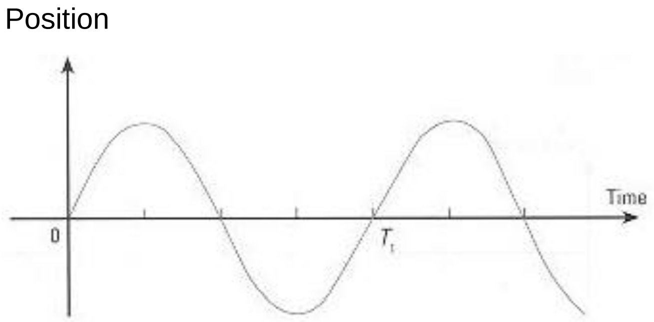


Tuning fork with long prongs produces lower frequency.

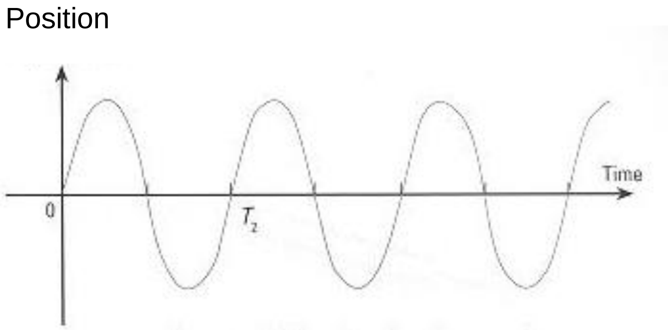


Tuning fork with short prongs produces higher frequency.

The two graphs below show the waveforms produced by the two tuning forks.



Waveform for longer tuning fork of lower frequency f_1 and thus longer period T_1.

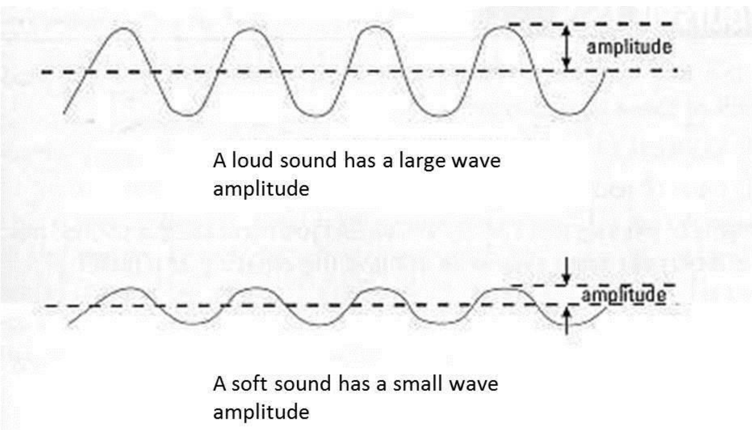


Waveform for shorter tuning fork of higher frequency f_2 and thus shorter period T_2.

Loudness

The loudness of a sound is subjective. What is soft music to you may be perceived as loud by your neighbour. Generally, a louder sound has a larger wave amplitude compared to a softer sound.

The amplitude of a wave is related to the amount of energy transferred by the wave. To create a wave with larger amplitude, the source of the wave must have a greater vibration or oscillation.



As we move further away from a point source of sound, the sound we hear gets softer.

Question:

As the sound from an alarm propagates in all three dimensions, the sound gets softer as the distance between the receiver and the alarm increases. There are two reasons for this **attenuation**:

1. Air is not a perfectly elastic medium and therefore the sound it carries suffers some **damping** effect. The energy of the sound wave is lost to the medium itself.
2. There is a spreading of waves and so the sound energy is distributed over a larger area.

Will the sound attenuated by a factor of $\frac{1}{r}$, $\frac{1}{r^2}$ or $\frac{1}{r^3}$, where r is the distance between the source and the receiver? Assume the damping effect is negligible, explain your answer.

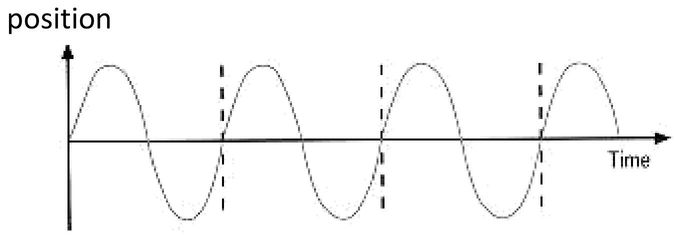
Solution:

The sound will diminished by a factor of $\frac{1}{r^2}$. The sound wave will propagate in a spherical shell which is proportional to r^2.

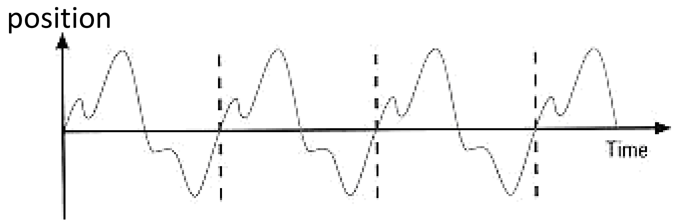
Timbre (or Sound Quality)

Tuning forks produce pure tones. A pure tone is a sound of a single frequency, which is represented by sinusoidal waveforms, such as the first wave shown on the next page. Our voice and musical instruments produce varying waveforms. Such waveforms are produced by adding different frequencies together.

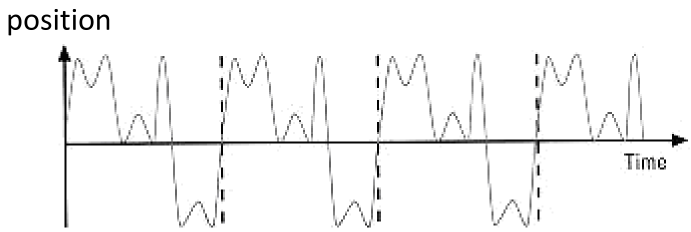
A tuning fork produces a sine curve.



Waveform produced by a flute.

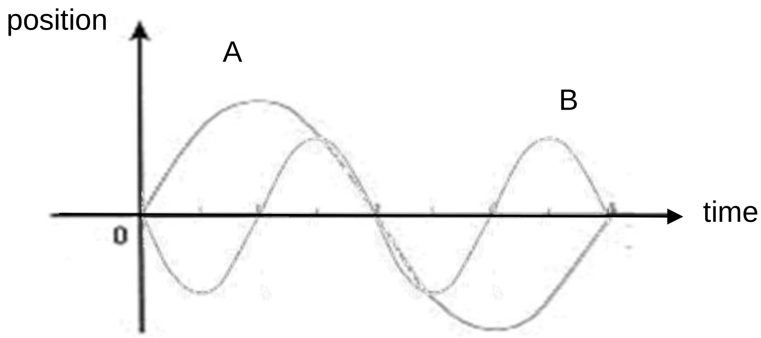


Waveform produced by a violin.



Check Your Understanding

1. An electronic synthesizer produces two pure notes A and B as shown.



Explain, using the above figure, if the following statements are true or false.

(i) A is louder than B.

True. Amplitude of A is larger than B

(ii) Pitch of A is higher than B.

False. A has a longer period, hence a lower frequency. Pitch of A is lower than B.

(iii) A and B have the same speed.

If both notes are traveling through air (at same temperature), they would have the same speed.

2. The frequencies of two musical notes, C4 (middle C) and C5 are 261.6 Hz and 523.2 Hz respectively. If they have the same amplitude, state if each of the statements below is true. If a statement is false, explain why.

(i) C5 has a higher pitch than C4.
True.

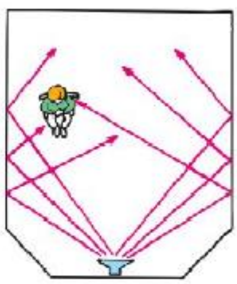
(ii) C5 is louder than C4.
False. Since both notes have the same amplitude, they are equally loud.

(iii) The wavelength of C4 is longer than that of C5.
If both notes are traveling through air, they have the same speed. Since C4 has a smaller frequency, from $v = f\lambda$, wavelength of C4 is longer.

16.7 BEHAVIOUR OF SOUND WAVE UPON INTERACTION WITH MATTER

Recall under the topic of Wave, when a wave reaches the boundary between one medium and another, part of the wave can undergo reflection, part of the wave can transmit across the boundary and refract in the other medium, while some part of the wave may be absorbed by the medium. Likewise, a sound wave can be reflected, refracted or absorbed when it is incident on a different medium, or the same medium with different physical properties.

Reflection of Sound Wave



Sound reflects from a smooth surface the same way that light does – the angle of incidence is equal to the angle of reflection. (See picture on left)

Reflection of sound waves off of surfaces can lead to one of two phenomena - an **echo** or a **reverberation**.

A reverberation often occurs in a small room, such that if a reflected sound wave reaches the ear within 0.1 seconds of the initial sound, then it seems to us that the sound is *prolonged.* This is due to the limitation of human hearing, that we can distinguish two sound waves if they reach the ear at least 0.1 second apart.

Question:

1. What is the maximum size of a room which the effect of reverberation can be detected by the ear?

$$2 \times \text{Size of room} = \text{Speed of sound} \times \text{Time limit for reverberation to occur}$$

$$\text{Size of room} = \frac{350 \times 0.1}{2}$$

$$= 17.5 \text{ m}$$

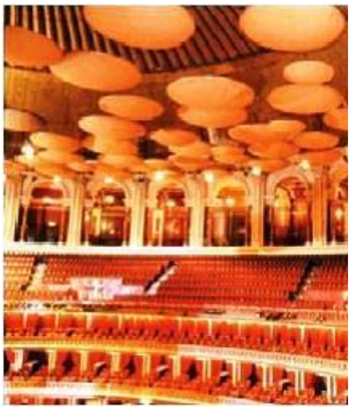
In the first step, we take into account that the distance of travel is twice the size of room because the sound wave has to be reflected back.

2. Many of us live in a room smaller than the size as described in the earlier question, why is it that we do not normally hear reverberations in our own room?

In a room that is filled with furniture, reflection is highly diffused. Other contributing factors are open door and windows do not allow reflection of sound waves, while soft surfaces such as bed sheet, mattress, and cushions are sound absorbing. Reverberations occur more frequently in empty houses.

Reflection of sound waves also leads to **echoes.** Echoes occur when a reflected sound wave reaches the ear more than 0.1 seconds after the original sound wave was heard. If the elapsed time between the arrival of the two sound waves is more than 0.1 seconds, then the sensation of the first sound will have *died out.* In this case, the arrival of the second sound wave will be perceived as a second sound rather than the prolonging of the first sound.

Question:

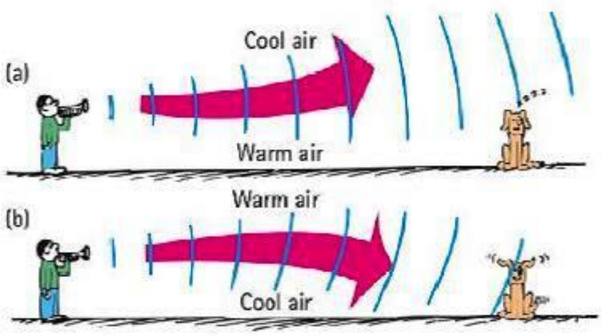


Reflecting surfaces are suspended above the stage in some concert halls as shown in the picture. They are large plastic reflectors that are somewhat curved which increases the field of vision. If you look up at these reflectors, you will see the images of the members of the orchestra. Why is it that the reflectors are placed in such a manner?

Solution:

Both light and sound follows the same law of reflection, so if a reflector is oriented so that you can see a particular musical instrument, rest assured that you will hear from it too. Sound from the instrument will follow the line of sight to the reflector and then to you.

Refraction of Sound Wave



Refraction of sound waves is most evident in situations in which the sound wave passes through a medium with gradually varying properties. For example, sound waves refract when travelling through air with varying temperatures. Even though the sound wave is not exactly changing media (still in air), it is travelling through a medium with varying properties (changing air temperature). Thus, the wave will refract and change its direction. In the day, the air directly above the ground tends to be warmer than the air far above the ground. Sound waves travel slower in cooler air than they do in warmer air. Subsequently, the direction of the wave changes continuously, refracting upwards towards the cooler air.

Sound refracts (bends) from warmer air to cooler air.

Question:

1. From our own experience, we can hear conversation over a longer distance at night. Why is this so?

   - Background noise is reduced considerably at night.
   - At night, the air near to the ground is cooler and so sound refracts toward the ground. Part of the sound wave that would have travelled upwards is bended toward the ground so a listener would be able to hear over a longer distance.

2. We can hear thunder when the lightning is relatively close to us, but if the lightning is far away from us, we often fail to hear the thunder. Why is this so?

   Distant thunders will also undergo refraction. Sound travels slower at higher altitudes and bends away from the ground, so you may not hear it.

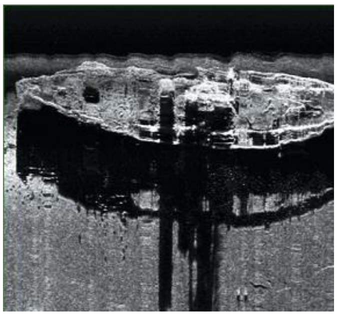
16.8 APPLICATIONS OF SOUND

Echolocation

Echolocation is the process determining the distance and direction of objects by using sound. Echolocation is performed by certain animals to locate food or obstacles in darkness, such as in caves and in the ocean. These animals, which include bats and toothed whales, produce sounds and then listen for echoes. The delay between the emission (sending out) of a sound and the arrival (detection) of an echo indicates the distance of an object from the animal.

The barn owl offers another way to detect prey; by listening to the sounds that the prey makes. Barn owls locate their prey by making use of the fact that each ear receives sounds at slightly different times if the owl's head is turned away from the source, due to the small difference in the distances travelled by the sound to reach each ear. This small difference is processed by the neural circuitry of the brain; the owl swivels its head until the waves reach both ears at the same time. At that null point, the head and eyes are facing directly at the sound source. Owls are capable of detecting time differences in sound waves received by each ear as small as 10 μs.

SONAR (**SO**und **N**avigation **A**nd **R**anging)



SONAR is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, communicate with or detect other vessels.

The picture on the left is a long lost steam ship which sank in 1898. Sonar works by transmitting an ultrasonic pulse of sound energy through air or water and sensing reflected waves from objects in the path of these waves. The frequency of the sound transmitted is about 50 kHz. When the sound waves reach an object, they are reflected in various ways, depending on the position, shape, orientation, and surface characteristics of the object.

Ultrasound scans

Sound with frequencies above the upper limit of the human range of audibility is known as ultrasound. Generally, we classify ultrasonic frequencies as those above 20 kHz (20 000 Hz). Ultrasound can be used to obtain images of the inside of the body. It is commonly used to examine the development of a foetus. Ultrasound pulses are sent into the body using a transmitter. The echoes reflected from any surface inside the body are received. By noting the time interval, the depth of the reflecting surface within the body can be known.

Medical Uses

Shock waves are used to break up kidney stones and gallstones without invasive surgery by means of a technique called *extracorporeal shock-wave lithotripsy*. A shock wave is produced outside the body and is then focused by a reflector or acoustic lens so that as much of its energy as possible converges on the stone. When the resulting stresses in the stone exceed its tensile strength, it breaks into small pieces and can be eliminated. See video.

Check Your Understanding

1. A boat sends out pulses of ultrasonic waves at intervals of 10 ms (milliseconds). The pulses of waves are reflected from the seabed and echoes are received back at the boat. Signals of two pulses of ultrasonic waves and, in between, an echo from the seabed are displayed in Fig. 1.

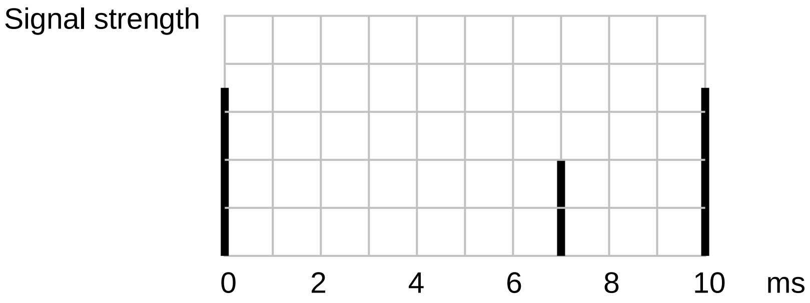


Fig. 1

(a) What is the time taken for a pulse to travel from the boat to the seabed and back, given that it is less than 10 ms?

7 ms

(b) The speed of sound in water is 1500 ms^{-1}. Calculate the depth of water below the transmitter of the ultrasonic waves.

Twice the depth of water = speed of sound x time interval between original signal and echo

$= 1500 \times 7 \times 10^{-3}$

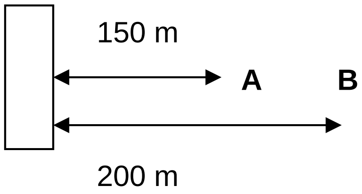
$= 10.5$ m

Depth of water = 10.5 / 2 = 5.25 m

(c) How and why will Fig. 1 change as the boat travels into deeper water?

Height of 2nd spike will be lower i.e. weaker signal strength of echo, as a larger portion of the energy of the sound wave is absorbed by the deeper water, and less returns to the receiver. The time separation between the echo and the initial signal increases as the sound wave takes a longer time to travel through the deeper water.

2. Two boys standing at A and B are in front of a tall building. The boy at A claps his hands and the boy at B, standing behind him, hears two claps 0.920 s apart. Calculate the speed of sound in air.



Claps heard at B:

1st one – sound from A to B

2nd one – sound from A to building, reflected back to B

Additional distance travelled by echo compared to original sound to reach B

= 200 + 150 – 50 = 300 m

Time difference = 0.92 s

So, speed of sound = 300 / 0.920 = 326 ms^{-1}

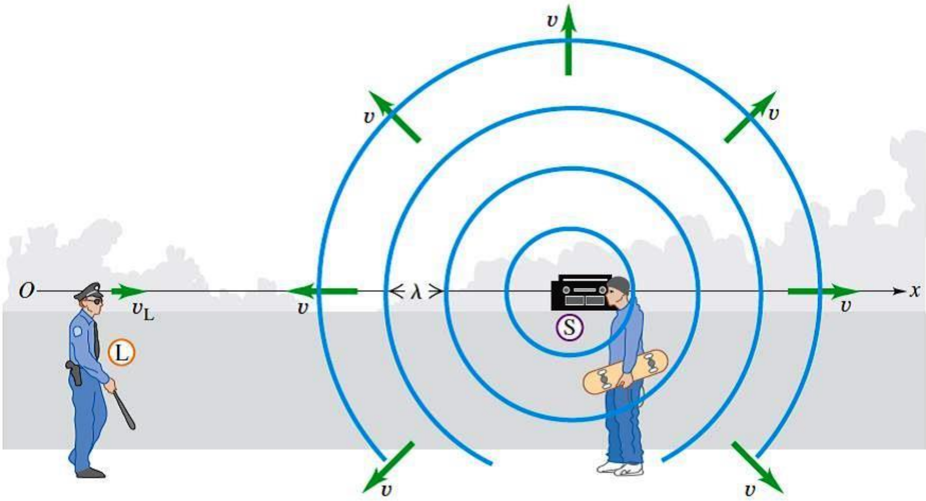
On Your Own

Look for one other application of sound and write down your notes here.

[SMTP / SSMT]

16.9 DOPPLER EFFECT

Moving listener (receiver)



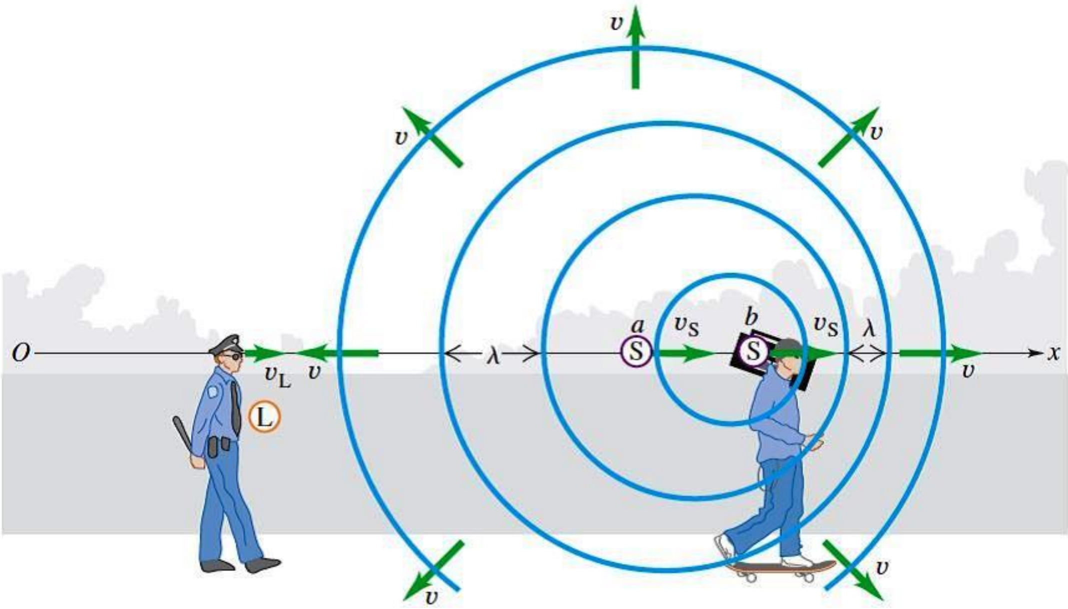
The picture above shows a listener (person on the left) moving toward a stationary sound source. The listener will hear a frequency that is higher than the source frequency because the relative velocity of listener and wave is greater than the wave speed v.

The waves approaching the moving listener have a speed of propagation of $v+v_L$ relative to the listener, so the frequency f_L with which the wave crests arrive at the listener's position (the frequency the listener hears) is

$$f_L = \frac{v+v_L}{\lambda} = \frac{v+v_L}{v/f_S} = \frac{v+v_L}{v}\,f_S$$

So a listener moving toward a source $(v_L > 0)$ hears a sound that has a greater frequency (higher pitch) than a stationary listener hears. Conversely, a listening moving away from the source $(v_L < 0)$ hears a sound that has a lesser frequency (lower pitch).

Moving source



Now suppose the source is also moving, with velocity v_S. The wave speed is still v relative to air; it is determined by the properties of the medium and is not changed by the motion of the source. But the wavelength is no longer equal to $\lambda = v/f_S$. Here's why:

The time for emission of one cycle of the wave is the period $T = \frac{1}{f_S}$. During this time, the wave travels a distance $vT = v/f_S$ and the displacement of the source is $v_S T = v_S/f_S$ (where v_S may be either positive or negative). The wavelength is the distance between successive wave crests and is determined by the relative displacement of the source and wave. As the second picture shows, this is different in front of and behind the source.

In the region to the right of the source, $\lambda = \frac{v}{f_S} - \frac{v_S}{f_S} = \frac{v - v_S}{f_S}$

In the region to the left of the source, $\lambda = \frac{v}{f_S} + \frac{v_S}{f_S} = \frac{v + v_S}{f_S}$

Combining this with the equation for the moving listener only, we have

$$\boxed{\begin{aligned} f_L &= \frac{v + v_L}{\lambda} \\ &= \frac{v + v_L}{v + v_S} f_S \end{aligned}}$$

For most purposes, we shall use the last equation. Remember that the equation is derived with v as the wave speed (scalar) and v_L and v_S as the *x*-components of the listener's and source's velocities.

Extension (I) Moving medium

The discussion thus far assumes that the air carrying the sound is still. If there is a gust of wind blowing in the positive *x*-direction with a magnitude of v_W, how would the last equation change?

$$f_L = \frac{(v - v_W) + v_L}{(v - v_W) + v_S} f_S$$

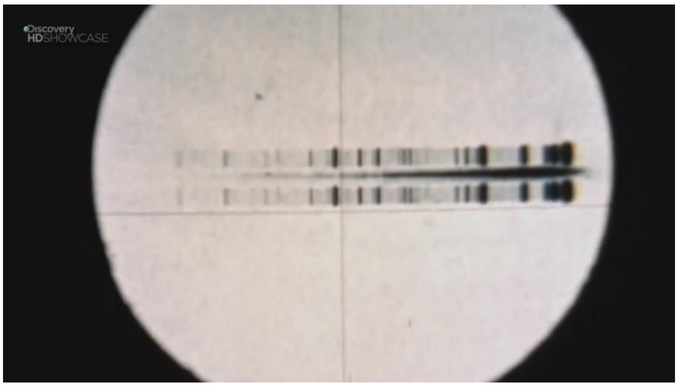
Extension (II) Doppler Effect for electromagnetic waves in vacuum

According to the special theory of relativity, the speed of light c is the same as measured by any observers, regardless whether he is moving or not. When a source emits radiation with frequency f_S, an observer moving away from the source with speed v observes a smaller frequency f_L given by

$$f_L = \sqrt{\frac{c - v}{c + v}} f_S$$

The particular effect is of great importance in cosmology. When we study the lights given off by the elements in distant galaxies, they are shifted toward longer wavelengths or higher frequencies. This Doppler shift is called **red shift** because the spectrum is shifted toward the red end of the spectrum and it provides solid proof that galaxies are moving away from us, hence the Universe is expanding.

Astronomer Edwin Hubble (1929). Hubble was the first person to provide experimental proof of an expanding universe.



The spectral profile of light from a distant galaxy showing a shift toward longer wavelengths (red shift)

If the source and the observer are moving toward each other, then v is negative and the f_L will be greater than f_S. This is called a **blue shift** and this effect has been observed in nearby galaxies such as the Andromeda galaxy moving toward the Milky Way under mutual gravitational attraction.

A last word on this section, the applications of sound in the previous section; echolocation, SONAR and ultrasound scans require the use of Doppler effect in order to be explained fully. Clearly, we do not expect the flying bat and its prey, the moth to be stationary source and "listener". Even in ultrasonic scans, Doppler effect enables the physician to see the beating heart of a fetus' beating heart as early as 11 weeks after conception (picture on right). Doppler effects are even observed in spectral shifts of atomic energy levels.

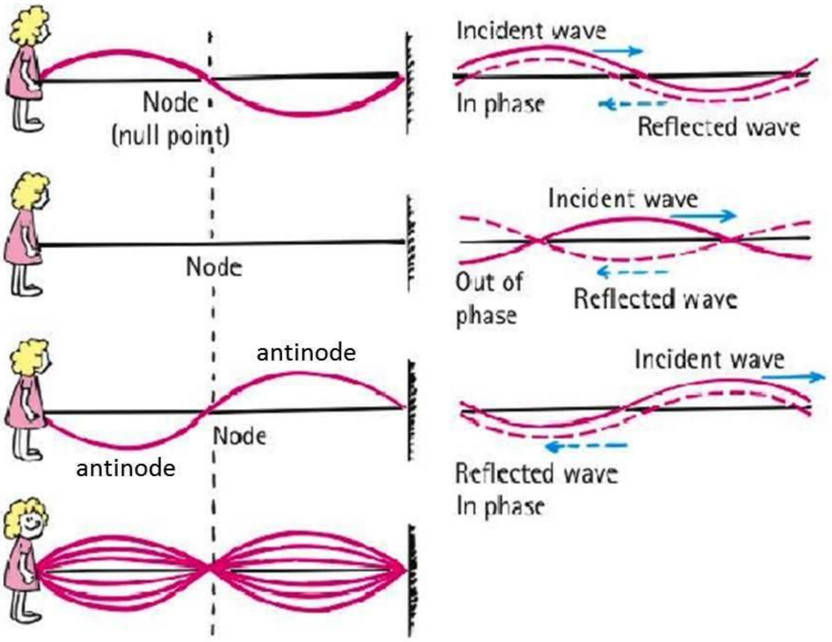
[SSMT]

16.10 STANDING WAVE

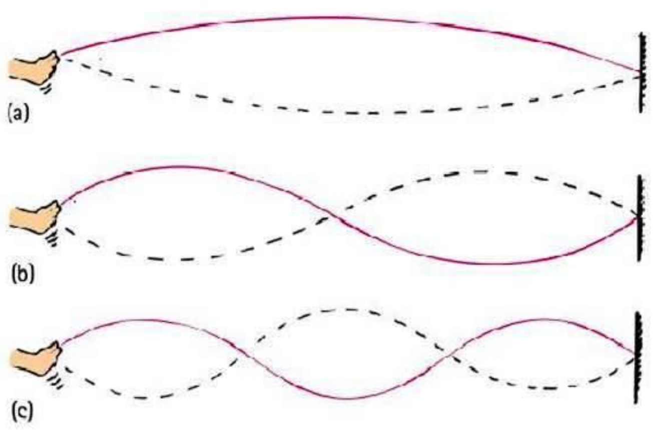
This section is an extension of the concept of wave interference and the principle of superposition that we have studied last year. A full description of the physics of standing wave is beyond the scope of the syllabus and so we shall only study some aspects of it.

If we tie a rope to a wall and shake the free end up and down, we produce a train of waves in the rope. The wall is too rigid to shake and so the waves are reflected back along the rope. By shaking the rope just right, we can cause the incident and reflected waves to form a **standing wave**, where parts of the rope, called the **nodes** appear to be standing still. **Antinodes** are regions of maximum displacement and maximum energy. Antinodes occur halfway between nodes.

Nodes: regions of minimal (**No d**isplac**e**ment) displacement and minimal or zero energy. No vibrations.
Antinodes: regions of maximum displacement and maximum energy. They vibrate with maximum energy.



Try it yourself: Making a standing wave



It is easy to make standing waves. Tie a rope to a firm support. Shake it from side to side. If you shake at the right frequency, you will set up a standing wave.

Shake at twice the original frequency, a standing wave of half the original wavelength will appear.

First you triple the first frequency, a standing wave of 1/3 the original wavelength will appear.

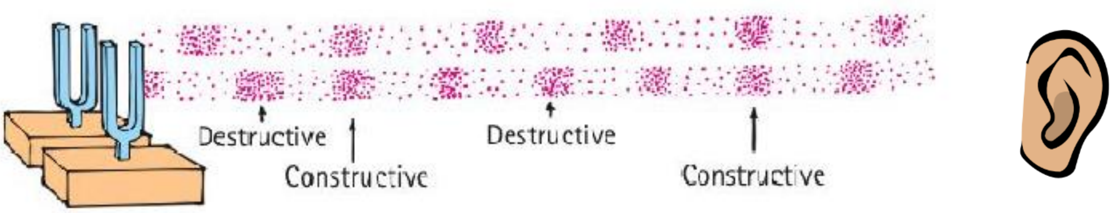
Standing waves are set up in the strings of musical instruments when plucked, bowed or struck. They are set up in the air in an organ pipe, a trumpet or a clarinet and the air of a plastic bottle when air is blown over the top. Standing waves can be set up in a tub of water or in a cup of coffee by sloshing the tub or cup back and forth with the right frequency. Standing waves can be produced in either transverse or longitudinal vibrations.

(Right: Example of longitudinal standing waves in a trumpet)

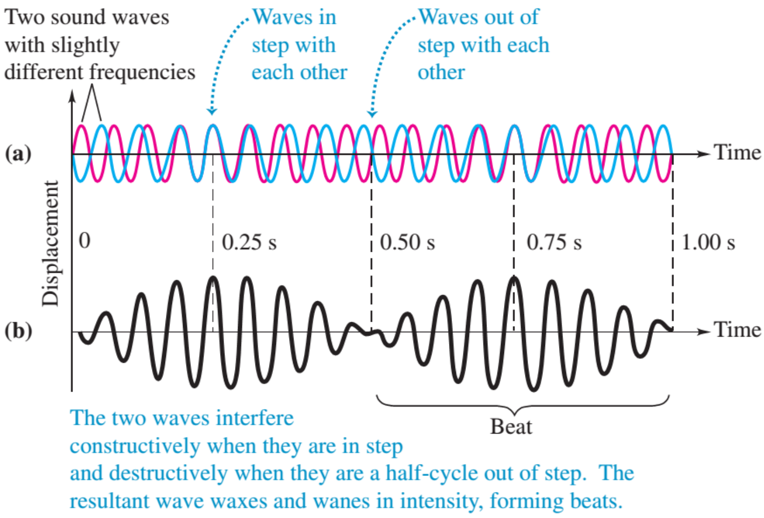
Standing sound waves have other phenomenal effects. See video.

16.11 BEATS

When two tones of slightly different frequencies are sounded together, a fluctuation in the loudness of the combined sounds is heard; the sound is loud then faint, then loud, then faint and so on. This periodic variation in the loudness of sound is called **beats** and is due to interference.



From the picture above, we can see two different tuning forks producing two “beams” of sound that are of slightly different frequencies. The two waves are travelling at the same speed but they produce crests and troughs at different times. Sometimes, they interfere constructively and produce a loud sound, at other times; they interfere destructively and produce a faint sound. The graphical representation is shown below.



Practical uses of beats

- tuning musical instruments: the musician listens for beats between the instrument and a standard frequency. When the frequencies are identical, the beats disappear.
- Radar guns of traffic police: The frequency that is sent out is different from the reflected frequency. The beats enable the traffic police to determine the speed of the speeding car.

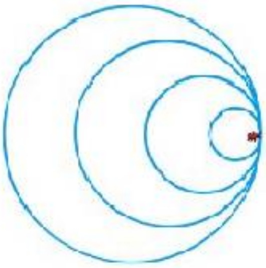
Questions:

1. What is the beat frequency when
   (a) a 262-Hz tuning fork and a 266-Hz tuning fork,
   (b) a 262-Hz fork and a 272-Hz fork are sounded together

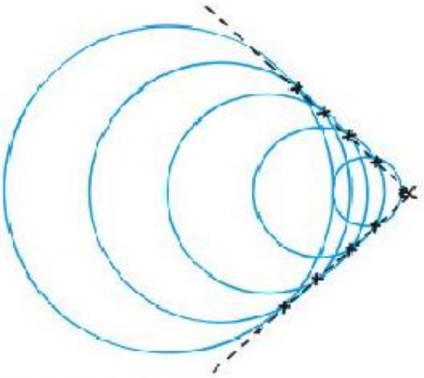
(a) Beat frequency of 4 Hz.
(b) Beat frequency of 10 Hz. Beat frequencies greater than 10 Hz are normally too rapid to be heard.

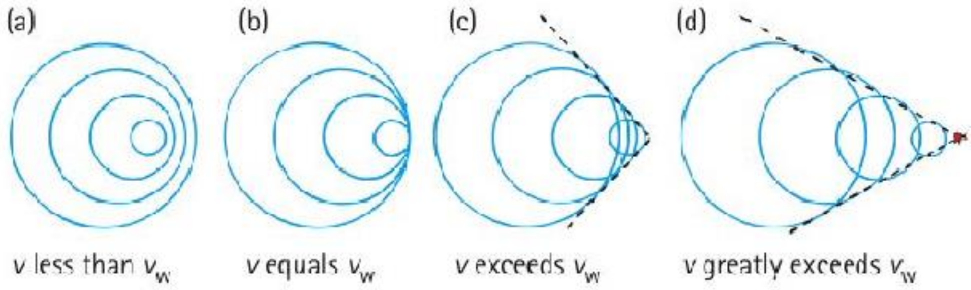
16.12 BOW WAVES

When the speed of a source is as great as the speed of the waves it produces, something interesting occurs. The waves pile up in front of the source. Consider a speedboat that moves as fast as the wave speed. Instead of moving ahead of the boat, the water waves superimpose and hump up one another directly in front of the boat. The speedboat moves along the leading edge of the waves it is producing.



When the speedboat moves faster than the wave speed, the waves it produces overlap at the edges (marked by points with X) and produce a familiar V shape, called a **bow wave**. This bow wave is not the typical oscillatory wave. It is a disturbance produced by overlapping many circular waves.





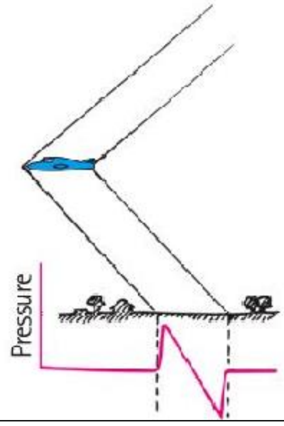
16.13 SHOCK WAVES

A supersonic aircraft similarly generates a three-dimensional **shock wave**. Just as a bow wave is produced by overlapping circles to form a V, a shock wave is produced by overlapping spheres to form a cone. This conical wave produced by the supersonic aircraft spreads until it reaches the ground. When the conical shell of compressed air reaches the ground, listeners will hear a sharp crack called a **sonic boom**.

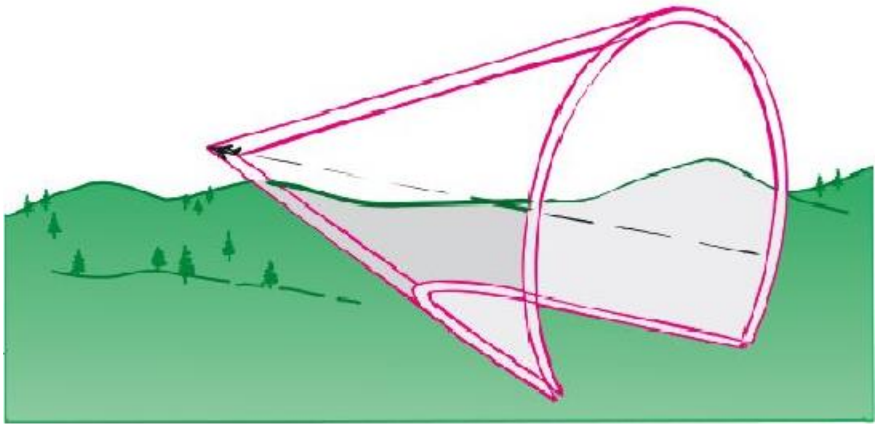
Sonic booms are not heard for subsonic aircraft because the sound waves that reach our ears are perceived to be a continuous one. Only when the aircraft exceeds the speed of sound do the waves overlapped and reach the listener in a single burst.

This aircraft is producing a cloud of water vapour that has just condensed out of the rapidly expanding air in the rarefied region behind the wall of compressed air.

Shock wave of a bullet piercing a sheet of Plexiglas. Light deflecting as the bullet passes through the compressed air makes the shock visible. Look carefully and see a second shock wave originating at the tail of the bullet.



The shock wave is actually made up of two cones – a high pressure cone with the apex at the bow of the aircraft and a low pressure cone with the apex at the tail of the aircraft. A graph of the air pressure at the ground level between the cones takes the shape of the letter N.



A shock wave sweeping across the ground.

It is not necessary for the moving source to be noisy to produce a shock wave. An example would be the whip. When a lion tamer cracks a circus whip, the cracking sound is actually a sonic boom produced by the tip of the whip when it travels faster than the speed of sound. The whip itself is not a sound source but when travelling at supersonic speeds, they produce their own sound as they generate shock waves.