Characteristics of Sound Waves

DEPARTMENT OF PHYSICS
The Open University of Sri Lanka

CHARACTERISTICS OF SOUND WAVES

Introduction

Sound is created only when something vibrates - a book is dropped on the floor, a pistol is fired, or a bell quivers after being struck. Each of these movements disturbs the air, the resulting air disturbance enters the ear and agitates the ear drum, the auditory never is excited and we experience the sensation of sound. It is the air disturbance, the physical cause of the sensation of sound that we study in this session.

The transmission of sounds

During the process of transmission, it is obvious that something passes from the sounding body to the ear, in order to produce the sensation of sound. From the motion of the sounding body we guess that some sort of wave motion passes outwards from it. It can be easily shown that a medium (air or some other medium) is indispensable for the propagation of sound.

All materials, however, can transmit sound waves, when a faint tapping or scratching sound is made at one end of a long table, on putting the ear to the other end of the table, this sound can be heard even when the sound is too faint to be heard and the ear is not placed close to the wood. This shows that the sound waves have been transmitted through the wood.

If you examine it carefully, you will notice that every source of sound or part of it vibrates when it is set to produce sound. We hope you are familiar with the prongs of a tuning-fork. The prongs of a sounding tuning-fork and the plucked string of a guitar can actually be seen to vibrate. The vibration of a drum or a bell may not be visible but they can often be felt; when they are checked by the hand the sound ceases.

Produced by The Open University of Sri Lanka
2015

Activity

What is vibration?

A **vibration** is a rapid to and fro motion which is continually repeated. The vibration of a prong of a tuning-fork may be investigated by attaching a bristle to one of its prongs, and drawing under it a smoke glass plate while the prongs are vibrating. (See Figure.01)

If a glass plate is moved with a uniform velocity the trace made by the bristle will be similar to the wave pattern shown in Figure. 02.

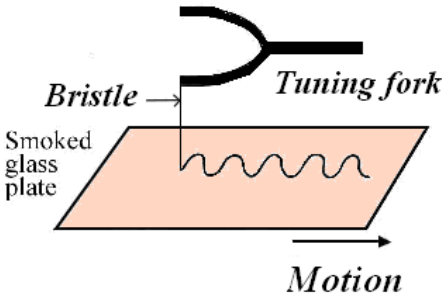


Figure 01

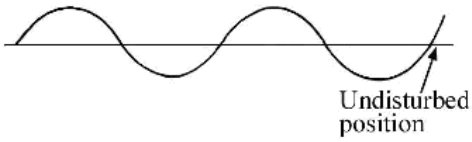


Figure 02

This particular type of vibration is the simplest possible, and is called simple harmonic motion as you know from earlier sessions.

Due to this vibration of the source of sound, the surrounding medium gets disturbed and this disturbance travel through the medium without the medium moving bodily with it. We call this is a wave,i.e. a wave allows energy to be transferred from one point to another some distance away without any particles of the medium travelling between the two points.

There are many kinds of waves such as light waves, radio waves, water waves and wave in stretching strings, rods and so on. All these waves can be divided into two main categories:

1. Transverse waves
2. Longitudinal waves

Now we shall discuss these two types in detail.

Transverse waves

A somewhat simple example of a transverse wave is seen when one end of a piece of rope or string is moved up and down in a direction perpendicular to its length. The particles of the rope near the end exert a drag on their neighbours so that these begin to oscillate as well. This process continues throughout the rope, until finally any particular particle is oscillating up and down slightly later than the one immediately before it and wave moves forward. A wave motion in which the medium moves in a direction perpendicular to the direction of the wave is called "transverse".

When a displacement of a particle is a maximum in the positive direction, i.e. above the rest position, that particle is said to be at the crest of a wave, whilst, when it is a maximum in the other direction, it is at a trough.

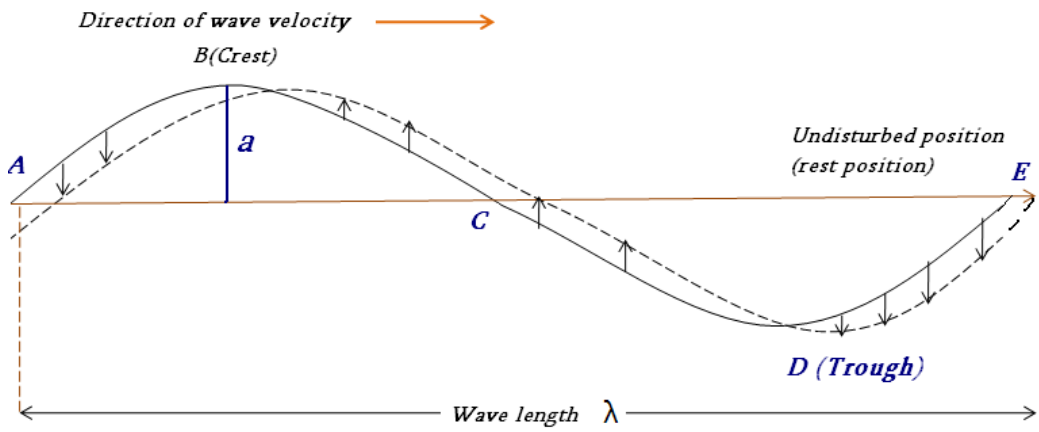


Figure 03

The net result is the rope presents the appearance of a series of equidistant crests and troughs which travel forward with a certain velocity, called the wave velocity. Now we shall define the term wave length. The wave length often denoted by (λ) is define as the distance between two successive particles which are at exactly the same point in their path and are moving in the same direction. Such pairs of particles are said to be in the same phase. Examples are A and E or B and F. (See Figure.03). From this definition, you should be able to understand that the distance from one crest

(or trough) to the next crest (or trough) can also be taken as the wave length.

The time taken for a wave to make one complete oscillation is called the periodic time (T). (A to E or B to F)

The number of complete oscillations made in one second is called the frequency (f).

$$f = \frac{1}{T}$$

The SI unit of frequency is called the hertz (Hz) and is defining as one cycle (or oscillation) per second.

Each time the source vibrates once, the wave form moves forward a distance λ. Thus in one second, when f vibrations occur, the wave moves forward a distance f λ.

But we know that the distance travel by the wave per second is the velocity, V of the waves.

Hence $V = f\lambda$ ……. (01)

This equation is true for all wave motion, whatever its origin: i.e. it holds good for sound waves, electromagnetic waves and mechanical waves.

Longitudinal waves

In contrast to a transverse wave, a longitudinal wave is one which the vibrations occur in the same direction as the direction of travel of the wave.

Sound waves are longitudinal waves, since the vibrations of air particles take place along the direction of travel of the waves owing to this longitudinal motion of the particles in the medium. Sound waves consist of a series of compressions followed by rarefactions. What we meant by compression is the pushing together of air particle and rarefaction is the moving apart of air particles.

Figure. 04 shows how a vibrating tuning-fork sends out a sound wave when the prongs move to the right (outwards) in compresses the air particles together. This disturbance is then transmitted

from particle to particle through the air, with the result that a pulse of compression moves outwards.

When the prongs moves inwards the air near them moves backward causing rarefaction (R). All the air particles move back in turn, with the result that the pulse of rarefaction travels outwards. Again the prongs move outwards, and a second compression (C) is sent out, and so on.

The distance between the canters of two adjacent compressions (C) or rarefaction (R) (i.e. the distance between two successive particles in the same phase) is called the wavelength of the sound and the same wave equation applies namely, $V = f\lambda$. It can be seen that the sound wave travels a distance equal to the wavelength while the fork *n* makes one complete vibration.

The velocity with which the wave travels does not depend on the rate it which the compressions are sent out from the source but on the rate at which the motion is passed through the air.

You will notice that it is convenient to represent a longitudinal wave by a displacement diagram which gives the displacement of the particles from the equilibrium position. Figure 05 illustrates the propagation of a longitudinal wave. This representation is similar to the wave form of a transverse wave but this representation should not be mixed up as the wave form for longitudinal waves. Here the row of dots shows the actual position of the particles.

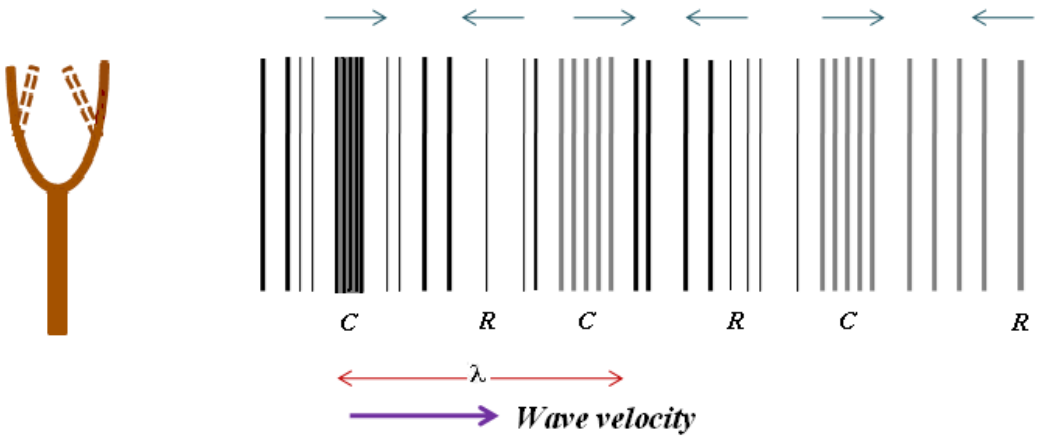


Figure 04 Sound waves from a tuning fork

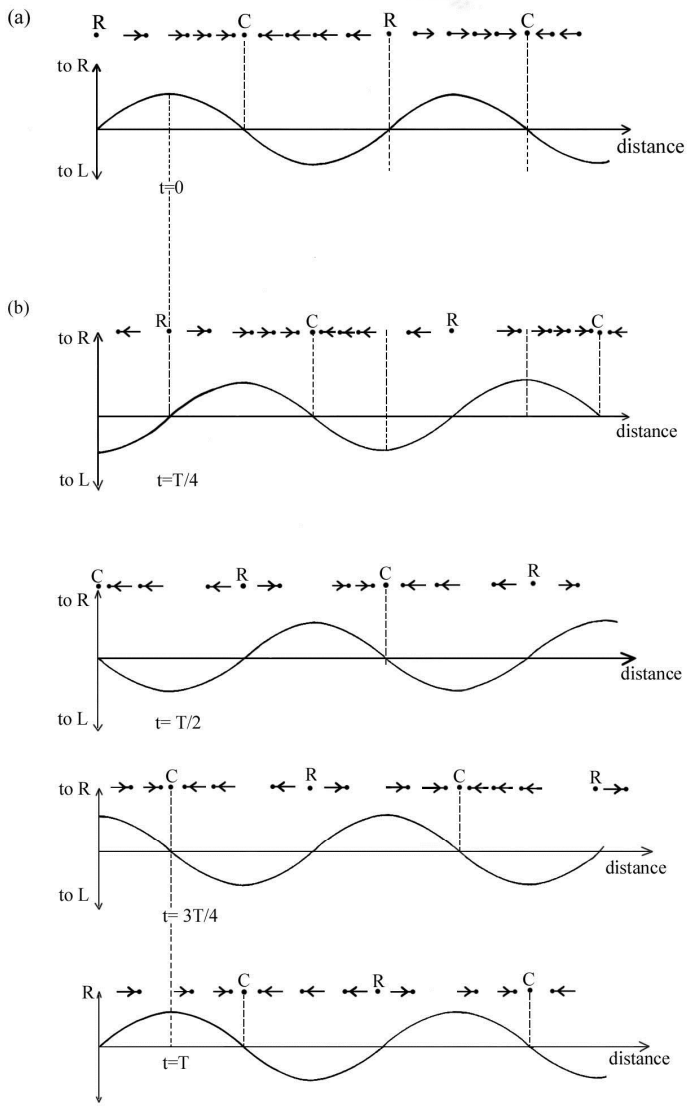


Figure 05 Longitudinal Waves

The diagram for t = T is, of course the same as t = o with displacements to right and to left. Note that the displacements of the particles cause regions of high density (C) and of low density (R) to be formed along the wave and also each particle vibrates about its mean position with the same amplitude and frequency.

Progressive waves

From the above discussion, you will notice that the wave profiles move along with the speed of the wave. Such waves are called progressive waves.

If a snapshot is taken of a progressive wave, it repeats itself at equal distances. The repeat distance is the wave-length λ. If one point is taken, and the profile is observed as it passes this point, then the profile is seen to repeat itself at equal intervals of time. The repeat time is the period, T.

The vibrations of the particles in a progressive simple harmonic wave are of the same amplitude and frequency. But the phase of the vibrations changes for different points along the wave.

The characteristic of sound waves

The sounds to which our ears respond may be divided in to two classes.

1. Sounds of short duration which change their character continually if they persist for some time; they are termed noises;

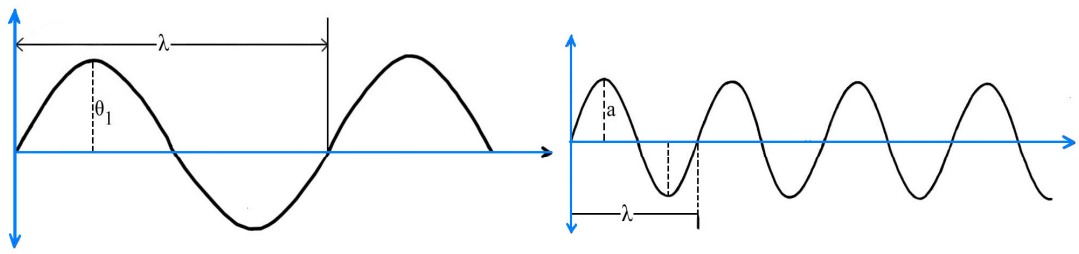
2. Sounds which are characterized by their smoothness and regular flow, as distinct from the irregularity and impulsive nature of noises, are termed musical sounds (notes).

A musical note possesses three characteristics, viz. Pitch, Loudness and Quality. The pitch of a note given out by a piano rises as we pass from the bass end of the keyboard to the treble. The loudness of the note depends on the force with which we strike the keys. The quality of note is that which distinguishes it from a note of equal pitch and loudness, sounded on a different instrument, e.g. a cello and a trumpet.

Let us discuss now what properties of a sound wave are responsible for these characteristics of a musical note.

Pitch

The pitch of a note is determined and measured by the frequency of vibration of the particles (i.e. number of vibrations per second) in the sound wave, which is equal to the frequency of the source. This means a high frequency gives rise to high-pitched note and a low frequency produces a low-pitched note. This is however analogous to colour in light, which depends on the wavelength or frequency of the light wave.



(a) Note of low pitch *(b) Note of high pitch*

Figure 06

The curves in figure 06 (a) and (b) may be used to represent the sound waves generated in the air by two tuning-forks. They are displacement diagrams which we discussed in an earlier section. Thus you can notice that the wave-length λ, of a sound of low pitch is longer than that of a sound of higher pitch.

Intensity and loudness

The intensity of a sound wave is a physical quantity and is defined as the rate of flow of energy per unit area perpendicular to the direction of the wave.

It can be shown that the intensity of a sound wave in air is proportional to:

I. The density of the air;
II. The square of the frequency; and
III. The square of the amplitude.

Loudness depends on the level of sensation caused on the ear drum. Obviously, the loudness of a sound will depend on its intensity, but it does not follow that loudness is directly proportional to the intensity. But normally, the greater the intensity, the greater the loudness of sound.

In the first instance, loudness depends on the varying pressure exerted on the ear drum by the incoming wave, and this will depend on the energy of the particles in the sound waves.

If they are vibrating violently, i.e. with large amplitude, they will cause large change of pressure on the ear-drum and a loud sound will be heard. The note represented by the wave trace in Figure. 06 (a) is louder than that in Figure. 06 (b) since the amplitude is greater.

At the same time, in (b) more waves strike the eardrum per sec than in (a): so if the amplitude of (b) had been equal to that of (a), then (b) would have been louder.

But this is not the only factor involved. The ear varies in its sensitivity to sounds of different frequencies. Generally speaking, the ear is more sensitive to the higher frequencies. Loudness is a sensation. Unlike intensities it can not be measured as it depends on the individual observer, in particular, the greater the intensity, the greater is the loudness of the sound.

Quality

If a particular note on a scale is played on two instruments, say, a piano and violin, it is easy to distinguish the tone of one instrument from that of the other, without seeing it. We say that the quality (or timbre) of the note is different in each case.

Generally speaking, instruments do not give tones which are pure in the sense that they consist of a single frequency only. It means that the waveform of a note is never simple harmonic in practice; the nearest approach is that obtained by sounding a tuning-fork as shown in Figure. 07 (a). If the same note is played on a violin and a piano respectively, the waveforms produced might be represented by Figure. 07 (b), (c), which have the same frequency and amplitude as the waveform in Figure. 07 (a).

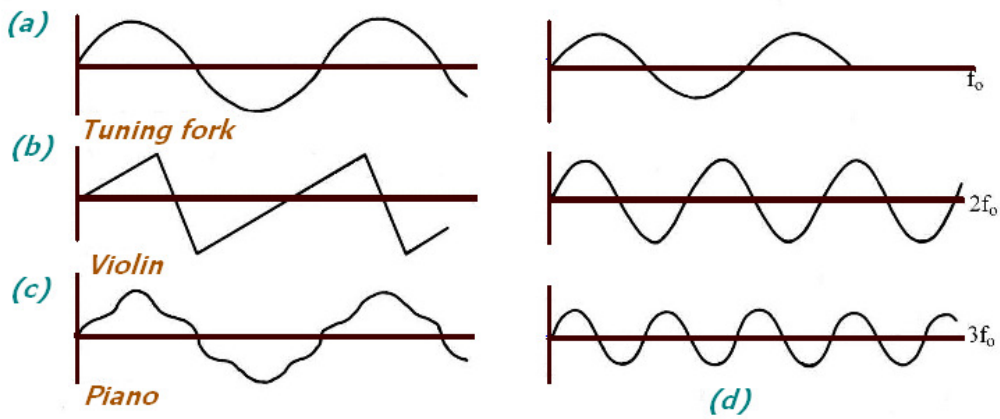


Figure 07

It can be shown mathematically that the curves of the shape of Figure. 07 (b), (c) are the result of adding a number of simple harmonic curves whose frequencies are multiples of f_0, the frequency of the original waveform; the amplitudes of these diminish as the frequency increases.

For example curve of Figure. 07 (c) might be analyzed as in Figure. 07 (d). When the note is sounded on the piano your ear registers the presence of note of frequencies $2f_0$ and $3f_0$ in addition to f_0 since it is able to detect simple harmonic waves. The amplitude of the curves corresponding to f_0 Figure. 07 (d) is greatest and it is heard predominantly because the intensity is proportional to the square of the amplitude. This frequency f_0 is called the fundamental. In the

background, however are the notes of frequencies, which are multiples of f_0 such as $2 f_0$ and $3 f_0$. These are called overtones.

As the wave form of the same note is different when it is obtained from different instruments, it follows that the wave form of a note of a frequency f_0 from a violin may contain overtones of frequencies $2f_{0,} 4f_0, 6f_0$ Therefore the musical "background" to the fundamental tone is different when it is sounded on different instruments, and hence the overtones present in a note determine its quality or timber.

Limits of audibility

The lowest note which can be distinguished by an average person has a frequency of about 20 Hz, while that of the height audible note is about 20000 Hz. These values vary considerably, however for different people, and the range decreases with age.

Longitudinal waves with a frequency of 50000 Hz are used in submarine signalling. At these waves are above audible frequency they are called "ultrasonic" waves. Again the "sounds" of explosions are sometimes of too low frequency to be heard. They are called "infrasonic" waves.

Self-assessment questions

1. Explain the difference between a transverse wave and a longitudinal wave. Of which type is a sound wave?

2. (a). How are the frequency and wavelength of a note related to the velocity of the sound wave?

(b). A vibrating loudspeaker cone produces sound waves with a frequency of 1000 Hz. What will be their wavelength in air if the speed is $340\,ms^{-1}$?

Solutions

1. In transverse wave displacement of the wave particle of the medium of which associates with the disturbance is at right angle to the direction of travel of the wave. But in longitudinal wave displacement associated with the disturbance is along the same direction as the direction of the travel of the wave.

   When the vibration of particles takes place along the direction of travel of the wave, then such waves are called longitudinal waves.

2. (a). If the velocity of sound wave is V

   Then $V = f\lambda$

   Where f is the frequency of the wave and λ is the wavelength of the wave.

   (b). Loudspeaker produces sound waves frequency 1000 Hz. Therefore air columns near the loudspeaker will vibrate with the same frequency.

   Frequency of sound wave, $f = 1000\,Hz$

The speed of sound wave $V = 340ms^{-1}$

Using the equation, $V = f\lambda$

$$\lambda = V/f$$

$$\lambda = (340/1000)\,m$$

$$\lambda = 34\,cm$$

Therefore wavelength of sound wave in air is 34cm

Learning out comes

After reading this session, you should be able to:

- Discuss basic ideas on how sound is created and propagated in a medium.
- Discuss the characteristic of sound, viz. Pitch, Intensity, Loudness and Quality in detail.

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First published: 1986

The Open University of Sri Lanka

Nawala, Nugegoda, Sri Lanka

OER Transformation 2015

Open Educational Resources
The Open University of Sri Lanka

Produced by The Open University of Sri Lanka
2015