Open Educational Resources
The Open University of Sri Lanka

Properties of Sound Waves

DEPARTMENT OF PHYSICS
The Open University of Sri Lanka

Properties of Sound Waves

OUSL OER
Open Educational Resources
The Open University of Sri Lanka

Introduction

This lesson is to present to you the general properties of sound waves viz. reflection, echo, refraction and diffraction and also the properties based on superposition of waves such as interference, beats and resonance.

Further, this lesson would enable you to state the conditions that should be satisfied for the reflection and the refraction of sound waves to be detected. You should able to describe the production of echoes and also to explain why sound can more easily heard during the night than during the daytime.

You will also be able to understand how constructive and destructive interference from the source of sound take place and also the phenomenon of beats which is an example of interference. Finally you should be able to understand the general principles underlying in resonance.

Produced by The Open University of Sri Lanka
2015

Reflection

Just as in light waves, the sound waves can also be reflected from a plane surface so that the angle of incidence is equal to the angle of reflection. This can be demonstrated by the following experiment.

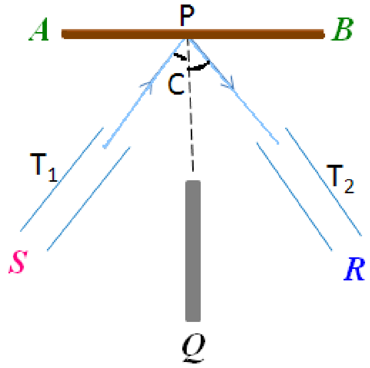

Figure 01 Reflection of sound waves

Two cardboard tubes (T_1 and T_2) which are inclined to each other, are placed in front of a plane surface AB (Cardboard or a Screen), as shown in Figure 01. A watch or a blowing whistle is placed at S and a detector such as a sensitive flame at R.

The screen Q placed at right angles to AB serves to prevent sound wave reaching the sensitive flame directly. Now the tube T_2 is directed towards P and moved until a sensitive flame is considerably affected at R, showing that the reflected wave passes in the direction PR. It will then be found that angle RPQ= angle SPQ. Hence the angle of incidence is equal to the angle of reflection.

It may also be shown that sound waves come to a focus after reflection when they are incident on a curved concave surface.

Echoes

Echoes arc produced by the reflection of sound from a hard surface such as a wall or a mountain cliff.

Let us suppose that a person claps his hands when standing at some distance away from a high wall and then listens to the echo. The time that elapses before the echo arrives, will depend on the distance of the wall from the observer. An echo occurs when the reflected sound wave returns to the observer 0.1 second or more after the original wave had reached him so that a distinct repetition of the original sound perceived. Here, you should note that the physiological sensation in the ear due to short sound persists for about 1/10 of second.

Since sound travels at $330ms^{-1}$ at normal temperature and pressure the reflected wave must have travelled a total distance of at least 33 m. 330×0.1 (Velocity x Time) and consequently the minimum distance should be about 16.5 m (33/2 m).

In an ordinary room sound undergoes 200 - 300 reflections before dying away. These results in a considerable prolongation of the sound known as reverberation, arid a rapid uniform distribution of sound throughout the room.

Every public speaker is aware that it is far less exhausting to address an audience in a hall rather than in the open air, because in the former, one's voice is "supported" by these reflections from time walls and the ceiling.

Refraction

Similar to light, sound can also be refracted when passing from one medium another of different density, i.e. it changes its direction, at the surface of separation of the media owing to its change in velocity.

This can be demonstrated by placing a watch in front of a balloon filled with carbon dioxide, which is heavier than air; it is found that the sound waves are heard most distinctly at a definite position on the other side of the balloon. The sound waves are thus seen to converge to a focus on the other side of the balloon. If the balloon is filled with hydrogen instead of CO_2, which is lighter than air, the sound waves diverge on passing through the balloon. This acts similarly to a diverging lens when light waves are incident on it.

Sound does not readily pass from one medium to another if its velocities in the two media are markedly different. Thus, when a sound wave in air strikes the surface of water most of the sound energy is reflected and very little is refracted into the water. Thus, to a swimmer under the water the sound in air would probably be inaudible. Similarly, sound does not pass readily from water to air. This fact is of great importance in the design of underwater sound receivers such as hydrophones by the refraction of sound. At day-time the upper layers of air are colder than the layer near to the earth. Now sound travels faster the higher the temperature, (We will discuss this in session five) and the sound waves hence refracted in a direction away from the earth (as shown in Figure 02). So the intensity of the sound waves diminishes. On the other-hand at night, layers of air near the earth are colder than that higher-up, and hence sound waves are now refracted towards the earth as shown in Figure 03 this result in an increase in intensity of sound waves.

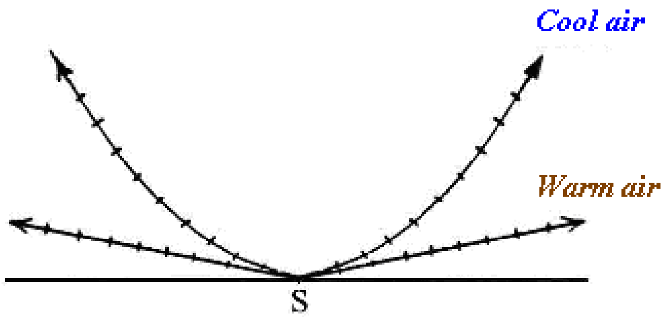

Figure 02 (a) Day time – Low Audibility at ground level.

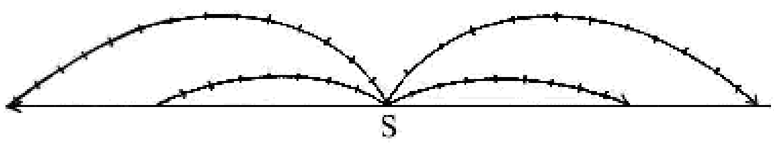

Figure 03 (b) Night times – High Audibility at ground level.

Interference

When two or more waves of the same frequency overlap, the phenomenon of interference occurs. Suppose two sources of sound, S_1, S_2 have exactly the same frequency and amplitude of vibration, and that their vibrations are always in-phase with each other. (See the figure 04) The combined effect of these two sources, at a point is obtained by adding algebraically the displacement at the point due to the sources individually; this is known as the principle of superposition.

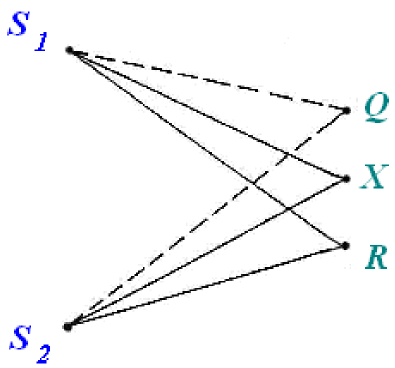

Figure 04 Interference of sound

If we consider point X which is equidistance from S_1 and S_2, the vibrations at X due to the two sources are always in phase as waves originally at S_1 and S_2 travelled an equal, distance of S_1X and S_2X respectively. This is illustrated in Figure 05 (a) and (b). The resultant vibration at X is obtained by adding the two curves, and is shown in Figure 05 (c). It has an amplitude double that of either curves or a frequency the same as either.

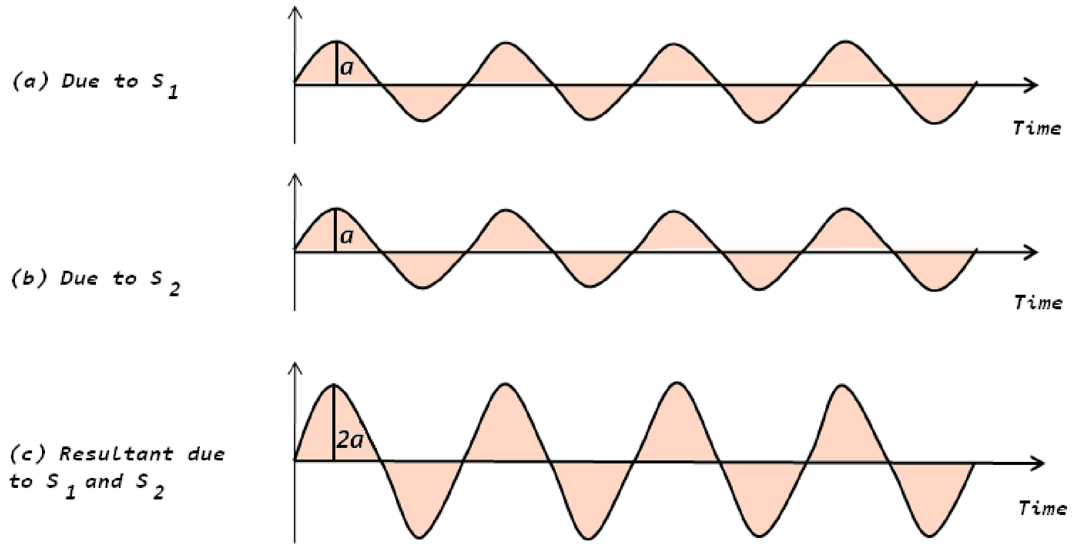

Figure 05 Vibrations at X

But the energy of the source of vibration is proportional to the square its amplitude. As such the sound energy at X is four times that due to S_1 or S_2 alone, the loud-sound is thus the heard at X. Therefore a permanent loud sound is obtained at a point such as Q if the path difference,

$S_1Q — S_2Q = m\lambda$

Where λ is the wavelength of sources S_1, S_2 and m is an integer.

Thus at Q we get constructive interference.

Now let us consider a point R in Figure 04 whose distance from S_2 is half a wavelength longer than its distance from S_1, i.e. $S_1R — S_2R = \lambda/2$

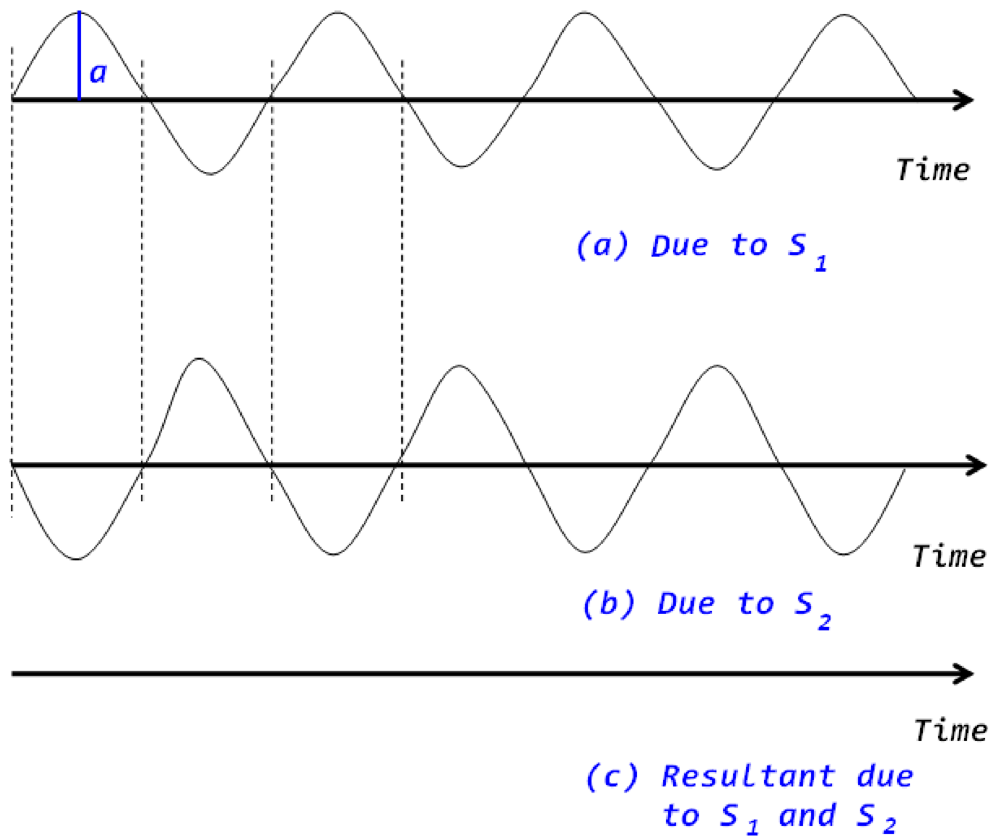

Figure 06 Vibrations at R

The vibration at R due to S_2 will then be out of phase by 180^0 with the vibration due to S_1. This is shown in Figure 06 (a) and (b).

The resultant effect at R is thus zero, as shown in Figure 06 (c); as the displacements at any instant are equal and opposite to each other.

At R no sound is heard and the permanent silence is said to be due to "destructive interference" between the sound waves from S and S_2.

Thus a permanent destructive interference is obtained at R if the path difference,

$S_1R — S_2R = n\,\lambda/2$, where n is an odd number.

Beats

When two notes of slightly different frequencies are sounded together the combined sound becomes periodically louder and softer. The effect is rather like a throbbing and the throbs are known as beats, and the frequency of beats is the number of intense sounds heard per second. Let us suppose two tuning forks A and B of frequencies 48 & 56 Hz respectively are sounded together. The variation of the displacement of the layer of air due to fork A alone is shown in Figure 07 (a); the variation of the displacement, of the layer due to fork B alone is shown in Figure 07 (b). According to the principle of superposition, the variation of the resultant displacement, of the layer is given by the algebraic sum of the two curves. This is illustrated in Figure 07 (c).

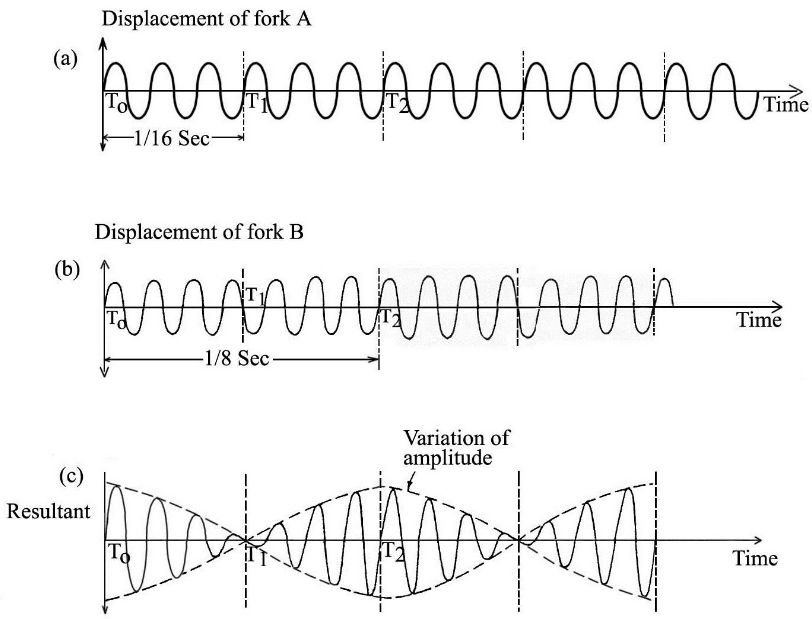

Figure 07 Beats

To understand this, suppose that the displacements of two forks are in phase at some instant T_o. Since the frequency of A is 48 cycles per sec (Hz) in $^1/_{16}$th second, variation of displacement due to A undergoes 3 complete cycles; at the same time, the variation of displacement due to B undergoes $3\,^1/_2$cycles (56 x $^1/_{16}$) since its frequency is 56 Hz.

Thus you can see the variation of displacement due to A & B separately are 180^O out of phase with each other at this instant, and their resultant displacement is then minimum at this instant as shown in Figure 07 (c). In $^1/_8$ th of a second from To, variation of the displacement of the layer due to A, B have undergone 6 & 7 complete cycles respectively. Hence in $^1/_8$ th of a second two waves are in-phase and their resultant at this instant is a maximum. In this manner a loud sound can be heard after every $^1/_8$ second, from which it follows that the beat frequency 8 cycles per second. This is simply the difference between the frequencies, 48, 56 of the two notes which we considered earlier.

Activity 01

What condition should be satisfied to hear only one beat?

Looking at the figure 07 you should be able to answer this question.

You can see that at time T_2, one beat is heard and that during that time fork B emits exactly one cycle more than the other fork A.

Let us now suppose two sounding-forks have frequencies f_1, f_2 cycles per second close to each other.

The number of cycle made by each fork in t second is $f_1 t$ and $f_2 t$ respectively. Assuming f_1 is greater than f_2 , condition to hear one beat in t seconds,

$f_1 t - f_2 t = 1$

Now if one beat has been made in t second s, then, $1/t$ is the number of beats per second or the beat frequency.

Beat frequency = $1/t$ = $f_1 - f_2$....................(01)

This phenomenon of beats can be utilized to measure the unknown frequency, f_1 of a note. To do this a note of known frequency f_2 is used to provide a beats with the unknown note. Now by counting the number of beats made in a given time, the beat frequency f can be obtained. Since $f$is the difference between f_2 and f_1, it follows that

$f = f_2 - f_1 \; or \; f = f_1 - f_2$

Therefore the unknown frequency would be$f_1 = f_2 - f \; or \; f_2 + f$.

Example

If $f_2 = 256 \; Hz$ and $f = 4 \; Hz$

Then f_1 = 252 Hz or 260 Hz

Now to decide which value of f_1 is correct we must perform another experiment. One prong of the fork of unknown frequency is loaded with a tiny piece of wax or plasticene or to reduce its frequency a little (i.e. f_1 is reduce), and the two forks are sounded again. If the beats are increased (i.e. $f$is increased),from the above equation you can see $f_1$must have been originally the lesser one; considering the equations $f_1 = f_2 - f \uparrow \; ; \; f_1 = f_2 + f \uparrow$.

i.e. $f_1 = 252 \; Hz$

If the beats are decreased, the frequency of the note must have been originally 260 Hz, considering equation

$f = f_2 - f_1;$

$f_1 = f_2 + f_1 \downarrow$

Here the tuning-forks must not be overloaded to avoid any error.

Activity 02:

Two sources of sound waves are emitting waves of wavelength 5m and 5.5m respectively. If the sound velocity is $340ms^{-1}$, what is the number of beats that will be produced?

Let $\lambda_1 = 5.0m$

$\lambda_2 = 5.5m$ and f_1, f_2 be the corresponding frequencies. Since $V=340ms^{-1}$ from equation

$V = f\lambda$

$$f_1 = \frac{v}{\lambda_1} = \frac{340\ ms^{-1}}{5.0\ m} = 68\ s^{-1}$$

$$f_2 = \frac{v}{\lambda_2} = \frac{340\ ms^{-1}}{5.5\ m} = 62\ s^{-1}$$

Number of beats = $f_2 - f_1 = 68 - 62 = 6\ \ s^{-1}$

Activity 03:

Using a 270 Hz tuning fork and sound from a certain piano note, a piano tuner hears six beats per second. Using 260 Hz tuning fork, he hears four beats per second. What is the frequency of the piano note?

Let f_1 be the frequency of the piano note.

From eq. 01 we known that,

Beat frequency = difference of the two frequencies which sounded.

Therefore, when tuner uses a 270 Hz tuning fork 6 beats per second were heard means that the difference between 270 and f_1 is equal to 6.

i.e. $f_1 = 270 + 6 = 276\ Hz\ or\ f_1 = 270 - 6 = 264\ Hz$

Also when tuner uses a 260 Hz tuning fork four beats occurred.

i.e. $f_1 = 260 + 4 = 264\ Hz\ or\ f_1 = 260 - 4 = 256Hz$

Since the piano note has a unique frequency it follows that $f_1 = 264\ Hz$

Resonance

When a vibrating tuning fork is held in the air the sound it generates is feeble. If, however, its stem is placed on a table, the sound is much louder. The vibrations of the fork are communicated to the table top, which is able to set far more air in vibration than the prongs of the fork alone. The vibrations of the table top are called forced vibrations, and their frequency is equal to the "forcing" frequency of the fork.

The phenomenon of forced vibrations may be investigated by the following experiment. A number of simple pendulums of slightly differing lengths. (See Figure 08), and having bobs consisting of small card-board cones, are suspended from a stretched horizontal cord.

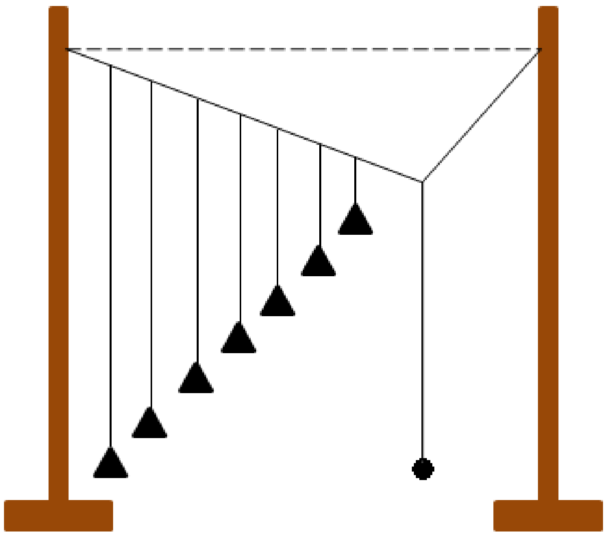

Figure 08 Demonstration of Resonance

Attached to the same cord is another pendulum with a large iron bob and of length equal to that of the middle pendulum of the series.

When the large pendulum is set in vibration, its motion is transmitted via the cord to the other pendulums.

Now you should observe what happens to these. After a time, they will be seen to swing, but you will notice that the amplitudes of their swings are not all the same. Besides, their frequencies are the same, as that of the heavy pendulum.

This is of course an example of forced vibration. The light pendulums are being driven by the heavy one, and forced to vibrate at its frequency. It will be noticed that the light pendulum which has the largest amplitude is that the natural frequency of which is closest to the frequency of the driving pendulum. By making slight adjustments to the length of this particular light pendulum it should be possible to arrange for its frequency to be exactly the same as that of the driver pendulum, where its amplitude will be found to be a maximum. When this happens we say that it is in ‘resonance’ with the driving pendulum.

The general principle which is involved may be stated briefly thus: The amplitude of forced oscillations is greatest when the driving frequency is equal to the natural frequency of oscillation of the driven system. Some examples are:

i. When a train is travelling the windows of nearby houses may be liable to vibrate.

ii. When troops are crossing a bridge, they are ordered to break step, in case the frequency of their steps coincide with the natural frequency of oscillation of the bridge. The resonance causes oscillations to build up and might damage the bridge.

Learning Outcomes

After reading this session, you should be able to:

- Discuss the general properties of sound waves.
- Discuss the production of echo and explain why sound can be more easily heard during the night time than day time.
- Discuss the interference and resonance.

Self-assessment questions

(1.) Two men stand facing each other, 200 meters apart, on one side of a high wall and at the same perpendicular distance from it. When one fires a pistol the other hears a report 0.6 second after the flash and a second report 0.25 second after the first.

Explain and calculate

i. Velocity of sound in air
ii. The perpendicular distance of the men from the wall.

(2.) A tuning fork of unknown frequency produces four beats per second with a standard source of frequency 240 Hz.

(a) What are the possible values of the unknown frequency?

(b) A small piece of wax attached to a prong of the tuning fork increased the number of beats heard per second. What is the true frequency of the tuning fork?

Produced by The Open University of Sri Lanka
2015

Solutions

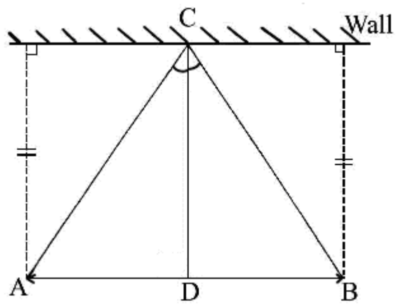

Figure 09

1. Let A & B be two men standing facing each other. When A fires a pistol B hears reports from sound waves emitted directly from the source and then reflected the sound waves from the wall.

    i. i.e. time taken for sound waves to travel from A to B is 0.6 sec. Since distance AB=200m

    200 = V x 0.6 where V is the velocity of sound waves in air

    $$V = \frac{200}{0.6} ms^{-1}$$

    $V = 333.5$ ms^{-1}

    ii. Second report is heard 0.25 second after the first. i.e. total time taken for sound waves to travel from A to C then to B is (0.6 sec.+0.25 sec.) which is equal to 0.85 sec.

    $$AC + CB = V \times 0.85 = \frac{200}{0.6} \times 0.85\text{m} = 283.3\text{m}$$

Since A & B stands at the same perpendicular distance from the wall we can conclude AC=BC; (also by considering the laws of reflection)

$$AC = BC = \frac{283.3}{2}\text{m} = 141.65\text{m}$$

Also it can be shown

$$AD = DB = \frac{200}{2} m = 100m$$

From trigonometry:

$$DC = \sqrt{AC^2 - AD^2}$$

$$DC = \sqrt{(141.65)^2 - (100)^2}$$

Therefore perpendicular distance of the men from the wall = 100 m

2. (a). If the unknown frequency of the tuning fork is f_1 and the standard frequency is f_2 then

Beat frequency: $f = f_1 - f_2 \; or - - - - - - - - -(1)$

$f = f_2 - f_1 - - - - - - -(2)$

Since $f = 4$ and $f_2 = 240 \; Hz$

$f_1 = (240 + 4) \; Hz \; or \; (240 - 4) \; Hz$

Therefore possible values of unknown frequencies are 244Hz and 236 Hz

(b). f_1 is reduce when a small piece of wax is attached to a prong of a tuning fork.

Since beats frequency f is increased, it should be noted that the second equation would satisfy this condition.

i.e. $f = f_2 - f_1$

$f_1 = f_2 - f = 240 - 4 \; Hz$

$f_1 = 236 \; Hz$

Course Team

Course Team Chair

Prof. E. M. Jayasinghe

Authors

Mr. R. M. Gunasinghe
Mr. D.M. Nanda
Mr. L. S. G. Liyanage
Ms. R. D. Hettiarachchi
Mr. M. M. S. G. K. Tennakoon
Ms. D. R. Abeydeera
Mr. J. D. Vithanage
Mr. G. U. Sumanasekara
Ms. I. R. Wickramasinghe

Graphic Artist

Mrs. M. R. P. Perera
Ms. A. P. Jayasinghe

Web Content Developer

Ms. B. K. S. Perera

Content Editors

Prof. C. Dahanayake
Mr. D. M. Nanda

Editorial Assistants

Ms. H. G. Chandrani
Ms. W. D. M. Srikanthi
Ms. M. D. P. Alahakoon
Ms. P. D. Sumanawathi

Language Editor

Mrs. Nilminie Kannangara

Desktop Publishing

Mr. W. C. Deshapriya
Mrs. N. W. C. Kularatne

Course Review

Mr. D. L. N. Jayathilake

First published: 1986
The Open University of Sri Lanka
Nawala, Nugegoda, Sri Lanka

OER Transformation 2015

Produced by The Open University of Sri Lanka
2015