12. Study of Sound

- Sound waves
- Velocity of sound
- Reflection of sound
- The human ear, audible sound, infra sound and ultrasound

Can you recall?

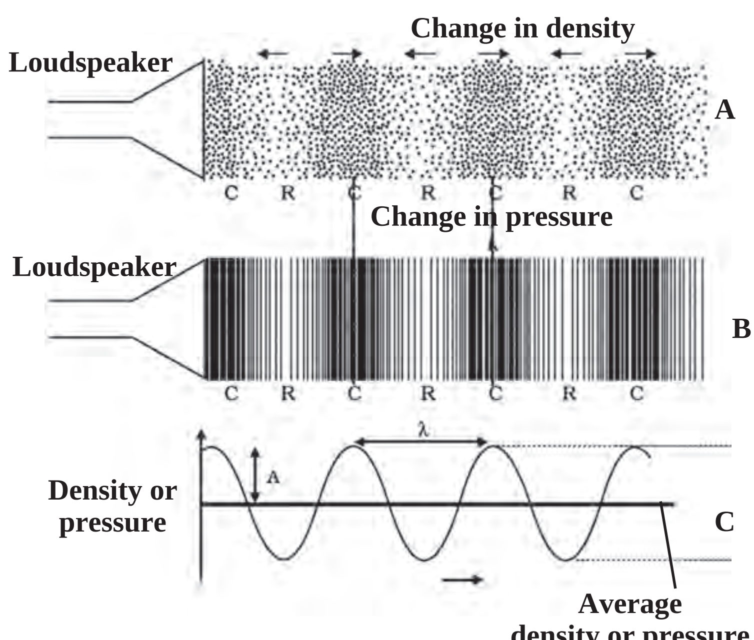
1. How does the velocity of sound depend on its frequency?
2. How is the direction of the oscillation of the particles of the medium related to the direction of propagation of the sound-wave?

Sound is a form of energy which creates the sensation of hearing in our ears. This energy is in the form of waves. A medium is necessary for the propagation of sound waves. Sound waves give rise to a chain of compression (place of higher density) and rarefaction (place of lower density) in the medium. The particles of the medium oscillate about their central or mean positions, in a direction parallel to the propagation of the wave. Such waves are called **longitudinal waves**. On the other hand, in the waves created by dropping a stone in still water, the particles of water oscillate up and down. These oscillations are perpendicular to the direction of propagation of the wave, such waves are called **transverse waves**.

Observe and discuss.

A sound wave can be shown in the form a graph. At any moment during the propagation of a sound wave we would find alternate bands of compression and rarefaction of the medium i.e. bands of greater and lesser density.

Figure 12.1 A shows the changes in density while figure B shows the changes in pressure. The changes in density or pressure are shown in the form of a graph in figure C.



12.1 Sound waves

The wavelength of sound waves is indicated by the Greek letter *lambda* (λ), while its frequency is indicated by *nu* (ν). The amplitude, which is the maximum value of pressure or density, is indicated by A. The time taken for one oscillation of pressure or density at a point in the medium is called the time period and is indicated by T.

The value of frequency determines the pitch (high or low) of the sound while the value of the amplitude determines its strength or loudness.

Research

1. How are the frequencies of notes ***sa, re ga ma, pa, dha, ni*** related to each other?
2. What is the main difference between the frequencies of the voice of a man and that of a woman?

Velocity of sound

Try this

1. Take your friend to a place where there are iron pipes e.g. the school verandah, a staircase or a fence.
2. Stand near one end of the pipe and ask the friend to stand 20 to 25 feet away from you near the pipe.
3. Ask the friend to gently tap the pipe with a stone. Press your ear to the pipe and listen to the sound coming through the pipe.
4. The same sound coming through the air can also be heard. But which sound reaches you first?

From the above activity you can see that you hear the sound through the iron pipe much before you hear it coming through air. This shows that sound travels faster in iron than in air.

The distance covered by a point on the wave (for example the point of highest density or lowest density) in unit time is the velocity of the sound wave.

$$\text{Velocity} = \frac{\text{Distance}}{\text{Time}}$$

Any point on the sound wave covers a distance equal to λ (wavelength) in time T (time period). Thus the velocity of sound is given by

$$\text{Velocity} = \frac{\text{Wavelength}}{\text{Time period}} \qquad v = \frac{\lambda}{T}$$

$$v = \upsilon \lambda \text{ because } \frac{1}{T} = \upsilon$$

Thus, the velocity of sound = wavelength x frequency.

In any medium at fixed physical conditions the velocity of sound of different frequencies is very nearly the same. The velocity is highest in solids and least in gases. It increases with an increase in the temperature of the medium.

The Italian physicists Borelli and Viviani, in the 1660s, first calculated the speed of sound. They measured the time between seeing the flash of a gun and hearing its sound from a long distance. Their value of 350 m/s is very close to the value of 346 m/s which is accepted today.

Velocity of sound in various mediums at 25^0C

State	Substance	Speed (m/s)
Solid	Aluminum	5420
	Nickel	6040
	Steel	5960
	Iron	5950
	Brass	4700
	Glass	3980
Liquid	Sea water	1531
	Pure water	1498
	Ethanol	1207
	Methanol	1103
Gas	Hydrogen	1284
	Helium	965
	Air	346
	Oxygen	316
	Sulphur dioxide	213

Velocity of sound in a gaseous medium: The velocity of sound in a gaseous medium depends on the physical conditions i.e. the temperature, density of the gas and its molecular weight.

Temperature (T): The velocity of sound is directly proportional to the square root of the temperature of the medium. This means that increasing the temperature four times doubles the velocity.

$$v \alpha \sqrt{T}$$

Density (ρ): The velocity of sound is inversely proportional to the square root of density. Thus, increasing the density four times, reduces the velocity to half its value.

$$v \alpha \frac{1}{\sqrt{\rho}}$$

Molecular weight (M): The velocity sound is inversely proportional to the square root of molecular weight of the gas. Thus, increasing the molecular weight four times, reduces the velocity to half its value.

$$v \alpha \frac{1}{\sqrt{M}}$$

Think

The molecular weight of oxygen gas (O_2) is 32 while that of hydrogen gas (H_2) is 2. Prove that under the same physical conditions, the velocity of sound in hydrogen is four times that in oxygen.

For a fixed temperature, the velocity of sound does not depend on the pressure of the gas.

Audible, infra- and ultra-sound

The limits of hearing of the human ear are 20 Hz to 20,000 Hz. That is, the human ear can hear sounds of frequencies in this range. These sounds are called audible sounds. Our ears cannot hear sounds of frequencies lower than 20 Hz and higher than 20,000 Hz (20 kHz). Sound with frequency smaller than 20 Hz is called infra sound. The sound produced by a pendulum and the sound generated by the vibrations of the earth's crust just before an earthquake are examples of such sounds. Sound waves with frequency greater than 20 kHz are called ultrasound.

The dog, mouse, bat, dolphin etc have a special ability to hear infra sounds. Thus, they can sense some noise which are inaudible to us. Children under 5 years of age and some creatures and insects can hear waves with frequency up to 25 kHz. Bats, mice, dolphins, etc, can also produce ultrasound.

A peep into the past

The Italian scientist Spallanzani was the first to discover a special mechanism present in bats. He covered various organs of bats like the eyes, ears, nose, etc. one by one and allowed them to fly in the dark thereby discovering how they can fly easily in the dark. He found that the bats with their ears covered began to collide with whatever came in their path. Even though their eyes were open. They were of no use to the bats. He thus discovered that their ability to fly in the dark depends on their ears and not eyes.

The ultrasonic sound produced by bats, gets reflected on hitting an obstacle. This reflected sound is received by their ears and they can locate the obstacle and estimate its distance even in the dark.

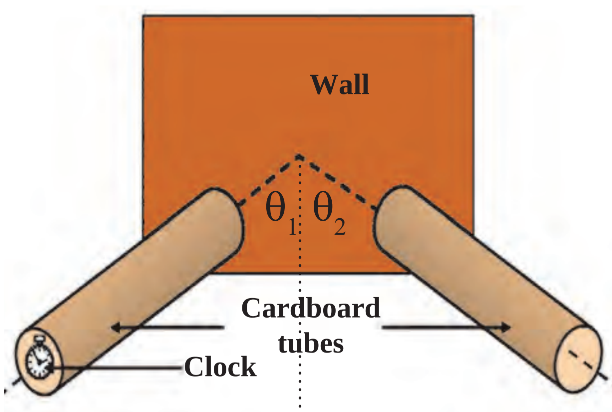
Uses of ultrasonic sound

1. For communication between ships at sea.
2. To join plastic surfaces together.
3. To sterilize liquids like milk by killing the bacteria in it so that the milk keeps for a longer duration.
4. Echocardiaography which studies heartbeats, is based on ultrasonic waves (Sonography technology).
5. To obtain images of internal organs in a human body.
6. In industry, to clean intricate parts of machines where hands cannot reach.
7. To locate the cracks and faults in metals blocks.

Reflection of sound

Try this

1. Make two sufficiently long, identical tubes out of a cardboard.
2. Arrange them on a table, in front of a wall as shown in figure 12.2.
3. Place a clock near the end of one of the tubes and try to hear the ticking of the clock at the end of the other tube by placing your ear there.
4. Adjust the angles of the two tubes till you can hear the sound very clearly.
5. Measure the angle of incidence θ_1 and the angle of reflection θ_2. Try to see if they are related in any way.



12.2 Reflection of sound

Like light waves, sound waves, too, get reflected from a solid or a liquid surface. These waves also follow the laws of reflection. A smooth or a rough surface is needed for the reflection of sound. The direction of the incident sound wave and reflected sound wave make equal angles with the perpendicular to the surface and all these three lie in the same plane.

Good and bad reflectors of sound

How much of the incident sound gets reflected decides whether a reflector is a good or a bad reflector. A hard and flat surface is a good reflector while clothes, paper, curtains, carpet, furniture, etc. absorb sound instead of reflecting it and, therefore are called bad reflectors.

Use your brain power !

In the activity on page no. 131, what will happen if you lift one of the tubes to some height?

Echo

You must have visited an echo point at a hill station. If you shout loudly at such a point, you hear the same sound just after a little while. This sound is called an echo.

An echo is the repetition of the original sound because of reflection by some surface.

In order to be able to hear the original sound and its reflection distinctly, at 22 ^{0}C, what must the minimum distance be between the source and the reflecting surface? At 22 ^{0}C, the velocity of sound in air is 344 m/s. Our brain retains a sound for 0.1 s. Thus, for us to be able to hear a distinct echo, the sound should take more than 0.1 s after starting from the source to get reflected and come back to us. Thus we can determine the minimum distance between the source and the reflecting surface as follows:

Distance = speed × time

= 344 m/s × 0.1 s

= 34.4 m

Thus, to be able to hear a distinct echo, the reflecting surface should be at a minimum distance of half of the above i.e. 17.2 m. As the velocity of sound depends on the temperature of air, this distance depends on the temperature.

Use your brain power !

1. To hear the echo distinctly, will the distance from the source of sound to the reflecting surface be same at all temperatures? Explain your answer.
2. When is the reflection of sound harmful?

Science in the surroundings......

Echo can be heard multiple times due to continuous or multiple reflections. The golghumat at Vijapur in Karnataka is an excellent example of this.

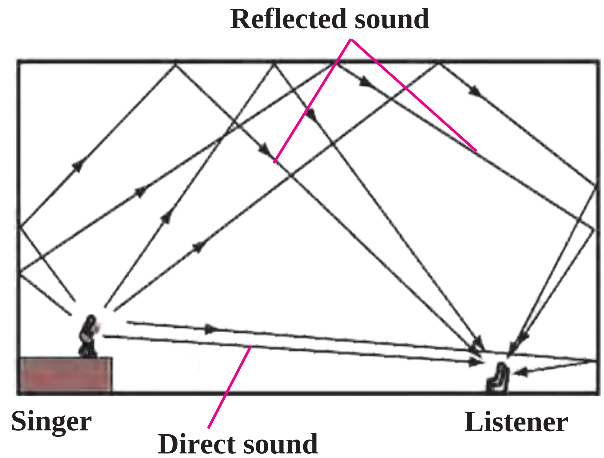
Reverberation

Compare the two cases:

1. Go to an empty, closed house with your friends.
2. Once inside, chat with your friends.
3. Note what you sense.

1. Close the doors and windows of your house and switch on the music system.
2. Increase the loudness of the system as much as possible.
3. Note what you sense.

Sound waves get reflected from the walls and roof of a room multiple times. This causes a single sound to be heard not once but continously. This is called reverberation. The time between successive reflections of a particular soundwave reaching us becomes smaller and the reflected sounds get mixed up and produce a continuous sound of increased loudness which cannot be deciphered clearly. This is the reason why some auditoriums or some particular seats in an auditorium have inferior sound reception. This is shown in figure 12.3.



12.3 Reverberation

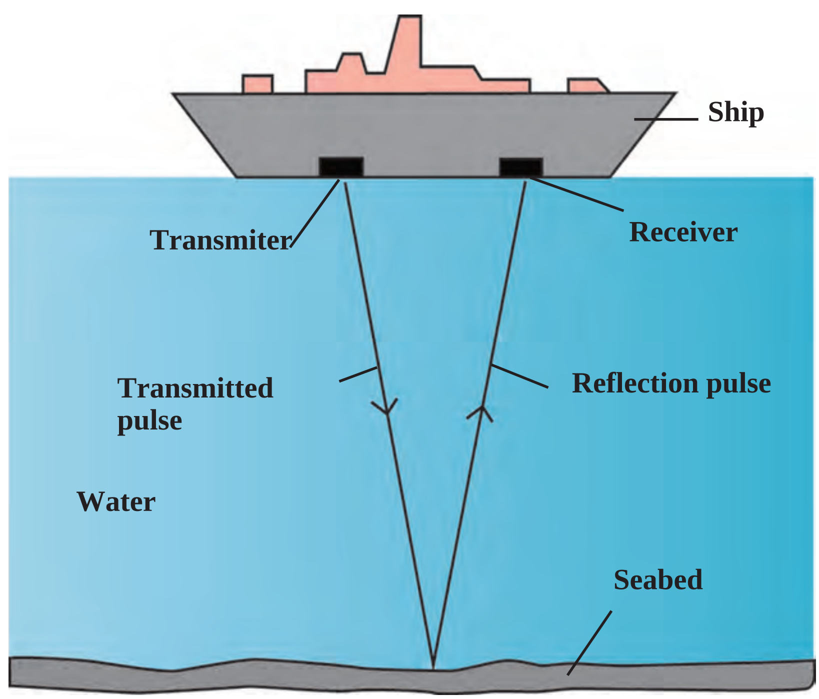
Use your brain power !

How will you reduce reverberation in public halls or buildings?

SONAR

SONAR is the short form for Sound Navigation and Ranging. It is used to determine the direction, distance and speed of an underwater object with the help of ultrasonic sound waves. SONAR has a transmitter and a receiver, which are fitted on ships or boats.

The transmitter produces and transmits ultrasonic sound waves. These waves travel through water, strike underwater objects and get reflected by them. The reflected waves are received by the receiver on the ship.



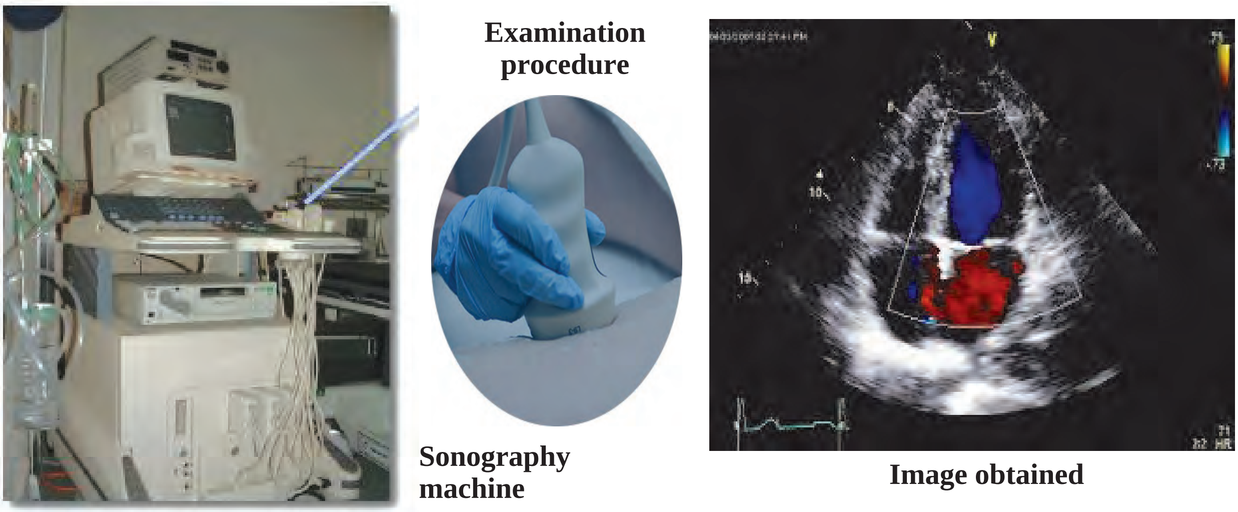
12.4 The SONAR technique

The receiver converts the ultrasonic sound into electrical signals and these signals are properly interpreted. The time difference between transmission and reception is noted. This time and the velocity of sound in water give the distance from the ship, of the object which reflects the waves.

SONAR is used to determine the depth of the sea. SONAR is also used to search underwater hills, valleys, submarines, icebergs, sunken ships etc.

Sonography

Sonography technology uses ultrasonic sound waves to generate images of internal organs of the human body. This is useful in finding out the cause of swelling, infection, pain, etc. The condition of the heart, the state of the heart after a heart attack as well as the growth of foetus inside the womb of a pregnant woman are studied using this technique.



12.5 Sonography machine and images obtained

This technique makes use of a probe and a gel. The gel is used to make proper contact between the skin and the probe so that the full capacity of the ultrasound can be utilized.

The gel is applied to the skin outside the internal organ to be studied. High frequency ultrasound is transmitted inside the body with the help of the probe. The sound reflected from the internal organ is again collected by the probe and fed to a computer which generates the images of the internal organ. As this method is painless, it is increasingly used in medical practice for correct diagnosis.

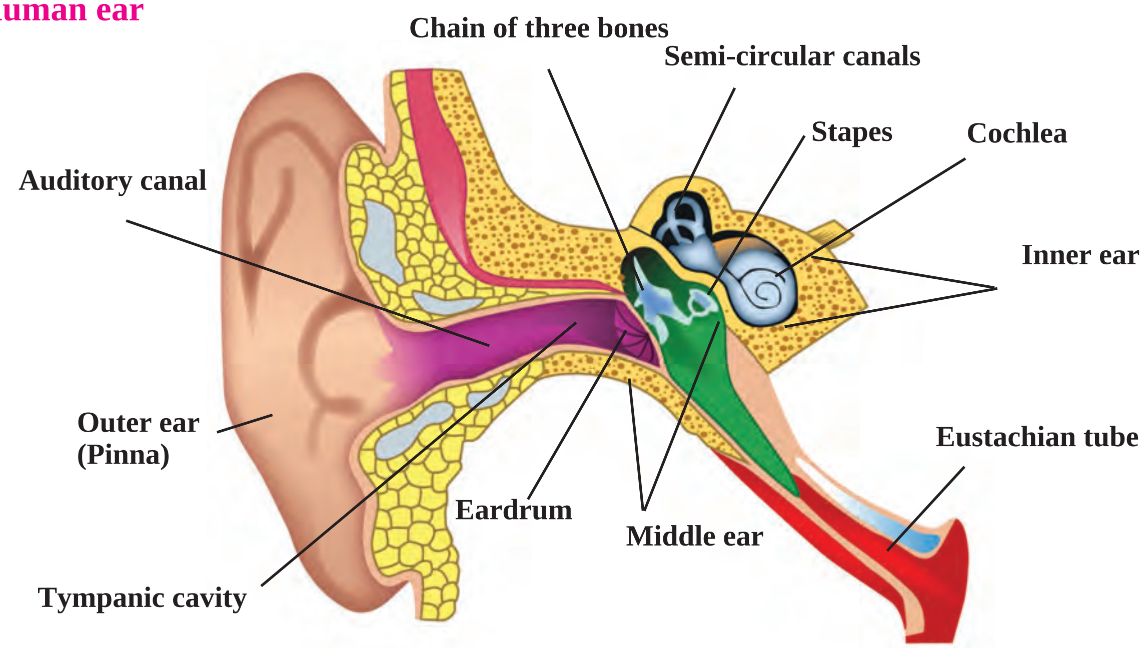
Find out

How is ultrasound used in medical science?

Always remember

Developments in science have led to advances in technology which have helped us make much progress. However, every coin has two sides and the misuse of science has had serious consequences for human life. The sonography technique can help to follow the growth and well being of an unborn baby. But the increasing incidence of female foeticide as a result of the discrimination between the girl and the boy child is an example of the grave misuse of this technique. Female foeticide is now a cognizable offence under the PNDT Act.

Human ear



12.6 Structure of the human ear

The ear is an important organ of the human body. We hear sounds because of our ear. When sound waves fall on the eardrum, it vibrates. These vibrations are converted into electrical signals which travel to the brain through nerves. The ear can be divided into three parts: 1. Outer ear 2. Middle ear 3. Inner ear.

Outer ear or Pinna

The outer ear collects the sound waves and passes them through a tube to a cavity in the middle ear. Its peculiar funnel like shape helps to collect and pass sounds into the middle ear.

Middle ear

There is a thin membrane in the cavity of the middle ear called the eardrum. When a compression in a sound wave reaches the eardrum, the pressure outside it increases and it gets pushed inwards. The opposite happens when a rarefaction reaches there. The pressure outside decreases and the membrane gets pulled outwards. Thus, sound waves cause vibrations of the membrane.

Inner ear

The auditory nerve connects the inner ear to the brain. The inner ear has a structure resembling the shell of a snail. It is called the cochlea. The cochlea receives the vibrations coming from the membrane and converts them into electrical signals which are sent to the brain through the nerve. The brain analyses these signals.

Always remember

The ear is an important sensory organ. Sticks or other pointed objects should never be inserted into the ear for cleaning it. Also, one should not hear very loud music using earphones. It may cause grave injury to the eardrum.

Solved examples

Example 1 : How long will it take for a sound wave of 25 cm wavelength and 1.5 kHz frequency of, to travel a distance of 1.5 km?

Given : Frequency (υ) = 1.5 kHz

$= 1.5 \times 10^3$ Hz

Wavelength (λ) = 25 cm = 0.25 m

distance (s) = 1.5 km = 1.5×10^3 m

time (t) = ?

Velocity of sound = Frequency × Wavelength

$v = \upsilon \lambda$

$v = 1.5 \text{ x } 10^3 \times 0.25$

$v = 0.375 \times 10^3$

$v = 375$ m/s

$$\text{Time} = \frac{\text{Distance}}{\text{Velocity}}$$

$$t = \frac{s}{v} = \frac{1.5 \times 10^3}{375} = \frac{1500}{375} = 4 \text{ s}$$

The sound wave takes 4 s to travel the distance of 1.5 km.

Example 2 : Ultrasonic waves are transmitted downwards into the sea with the help of a SONAR. The reflected sound is received after 4 s. What is the depth of the sea at that place?

(Velocity of sound in seawater = 1550 m/s)

Given :

Velocity of sound in seawater = 1550 m/s

Time for echo to be heard = 4s

Time taken by sound waves to reach the bottom of the sea $= \frac{4}{2} = 2$ s

$$\text{Velocity} = \frac{\text{Distance}}{\text{Time}}$$

Distance = Velocity × Time

= 1550 x 2 = 3100 m

Depth of the sea at that place = 3100 m

Example 3 : Sound waves of wavelength 1 cm have a velocity of 340 m/s in air. What is their frequency? Can this sound be heard by the human ear?

Given : Wavelength = λ =1cm=$1 \text{ x } 10^{-2}$m, Velocity of sound = v = 340 m/s

$v = \upsilon \lambda$

$$\therefore \upsilon = \frac{v}{\lambda} = \frac{340}{1 \text{ x } 10^{-2}} = 340 \times 10^2$$

$\therefore \upsilon = 34000$ Hz

This frequency is higher than 20000 Hz and, therefore, this sound cannot be heard by the human ear.

The SONAR technology was first developed during World War I to detect enemy submarines. This technology can be used in air also. In fact, bats use this technique to detect obstacles in their path so that they can avoid them and fly freely even in the dark.

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Exercises

1. Fill in the blanks and explain.

a. Sound does not travel through …………

b The velocity of sound in steel is …............ than the velocity of sound in water.

c. The incidence of ……… in daily life shows that the velocity of sound is less than the velocity of light.

d. To discover a sunken ship or objects deep inside the sea, ... technology is used.

2. Explain giving scientific reasons.

a. The roof of a movie theatre and a conference hall is curved.

b. The intensity of reverberation is higher in a closed and empty house.

c. We cannot hear the echo produced in a classroom.

3. Answer the following questions in your own words.

a. What is an echo? What factors are important to get a distinct echo?

b. Study the construction of the Golghumat at Vijapur and discuss the reasons for the multiple echoes produced there.

c. What should be the dimensions and the shape of classrooms so that no echo can be produced there?

4. Where and why are sound absorbing materials used?

5. Solve the following examples.

a. The speed of sound in air at 0 ^{0}C is 332 m/s. If it increases at the rate of 0.6 m/s per degree, what will be the temperature when the velocity has increased to 344 m/s?

(Ans: 200 ^{0}C)

b. Nita heard the sound of lightning after 4 seconds of seeing it. What was the distance of the lightning from her?
(The velocity of sound in air is 340 m/s?)

(Ans: 1360 m)

c. Sunil is standing between two parallel walls. The wall closest to him is at a distance of 660 m. If he shouts, he hears the first echo after 4 s and another after another 2 seconds.

1. What is the velocity of sound in air?
2. What is the distance between the two walls?

(Ans: 330 m/s; 1650 m)

d. Hydrogen gas is filled in two identical bottles, A and B, at the same temperature. The mass of hydrogen in the two bottles is 12 gm and 48 gm respectively. In which bottle will sound travel faster? How may times as fast as the other?

(Ans: In A; Twice)

e. Helium gas is filled in two identical bottles A and B. The mass of the gas in the two bottles is 10 gm and 40 gm respectively. If the speed of sound is the same in both bottles, what conclusions will you draw?

(Ans: Temperature of B is 4 times the temperature of A.)

Project :

Collect information about the musical instrument called *Jaltarang* and find out how the different notes are produced in it.

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