Understanding

Sound

Through Fun Experiments

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1. Introduction

The world we live in is full of sounds with an immense variety. The sounds of temple bells,

the honking and hooting sounds of vehicles,

the songs of a cuckoo,

the splatter of rainwater on a tin roof…

These sounds and many more comprise the incredible richness of our auditory universe.

Some sounds are pleasing to the ear like those produced by musical instruments. Some sounds are dangerous and can harm our ears – like the sounds of blaring high-decibel speakers, or the sounds of explosives. There exist sounds that human ears cannot sense, but are audible to the ears of dogs.

But what exactly is a sound? How is it generated?

2. Sound begins as a vibration

The origin of a sound is a vibration. A vibration consists of rapid, back and forth or repetitive motion of an object or material. But not all vibrations can be heard as sounds. For a vibration to be heard it must satisfy two conditions. Firstly, the repetitive or back and forth motion that constitutes a vibration must happen rapidly, that is, at a sufficiently high rate or frequency. Secondly, the motion must be sufficiently strong. Let us illustrate these ideas with some examples.

Take a steel plate and steel spoon and strike hard the edge of the plate with the spoon. It makes a loud clanging sound, produced by the vibration in the plate. You can feel the vibration if you lightly touch the plate with your fingers. But you cannot see the vibration – the back and forth motion of the surface of the plate – since its movements are too microscopic to be seen by the naked eye. But the next demonstration resolves this issue since it involves larger movements.

Take a leather belt – the one that you use to tie your trousers – and perform two experiments with it.

Hold the buckle end of it in one hand and the far end in the other hand. Hold the two hands at the same level, sufficiently wide apart allowing the belt to be straight and horizontal. Now let the far end of the belt to gently fall, while continuing to hold the buckle end. Make sure the falling belt does not touch any other object. Does the belt make any sound? It does not.

Now holding the buckle end of the belt again with one hand, make a sharp, flicking movement of the belt, like that of a whip. You will hear a sharp sound that sounds like a whiplash.

We see that while a slow movement failed to produce a sound, a nearly identical movement performed rapidly produced a sound. The necessity of the first condition viz, of rapidity of movement is demonstrated above.

Now let us come to the second condition: the vibration must be sufficiently strong to produce sound. To demonstrate this, take a piece of string instead of the belt and try to make a flicking movement like you did with the belt before. Whether the movement of the thread is slow or rapid, it fails to produce a sound. The movement of the belt is strong – the heavy belt displaces a lot of surrounding air. The movement of the string is weak: the thin and light string cannot displace much air.

But the flicking movement of a belt is not exactly a vibration, you might now argue. It is not a back-and-forth motion, or a repetitive motion. You are right. Most sources of sound involve some form of back-and-forth or repetitive motion. So let us now modify the above demonstration with the belt slightly.

Hold the belt at the buckle end again, but this time gently spin it above your head like a ceiling fan. Initially do it a low rate, or frequency. Do you hear any sound? Probably not. Now gradually increase the frequency of spinning. You will notice that at a certain frequency the belt makes a whirring sound as it cuts the surrounding air.

Now repeat the same spinning movement with a light string. You will hear no sound no matter how fast you spin it.

There are two important properties of a vibration – frequency and amplitude.

3. Frequency and Pitch

We now know that vibration consists of an object or a surface moving back and forth. We encounter many such objects in our day to day life.

The simplest is a swing (*jhoola*) that swings back and forth carrying a child. Or a traditional Indian cradle that consists of a piece of cloth that is tied to the ceiling with ropes. Or consider a cork bobbing up and down on the surface of water. A more “scientific” example of such back and forth motion is a simple pendulum, which can be realized by a piece of rock suspended by a string.

An important property of any back and forth motion or vibration is the number of times per second that such motion occurs. It is called frequency. We do not really consider the above mentioned instances of back and forth motion (swing, cradle of pendulum) as examples of vibration because usually we associate the word vibration to a motion that produces sound.

The motion of a pendulum does not produce sound. Nor does a swing if the contact between the rope and the hooks to which it is suspended is free of friction. Why do these motions not produce sound? Because their frequencies are too low. We hear as “sounds” only vibrations that have a sufficiently high frequency.

Frequency is defined as the number of back and forth motions per second. It is measured in units called Hermann Hertz, named after a German scientist who did a lot of pioneering work on sounds. Therefore, 1 Hertz (denoted by Hz) equals one back-and-forth movement in 1 second.

Hermann Herz (1857 – 1894). German physicist who did pioneering studies on sound.

Humans can hear sounds only in the range of 20 Hz to 20,000 Hz. A swing 3 meters long makes 1 full swing in about 3 seconds, which amounts to about 0.3 Hz.

Take for example the wing beat frequency of a mosquito. It is about 450 to 600 Hz. That explains the annoying buzz of a mosquito as it flies close to your ears.

The wing beat frequency of bees is also in the same range – about 230 Hz, which can therefore be heard.

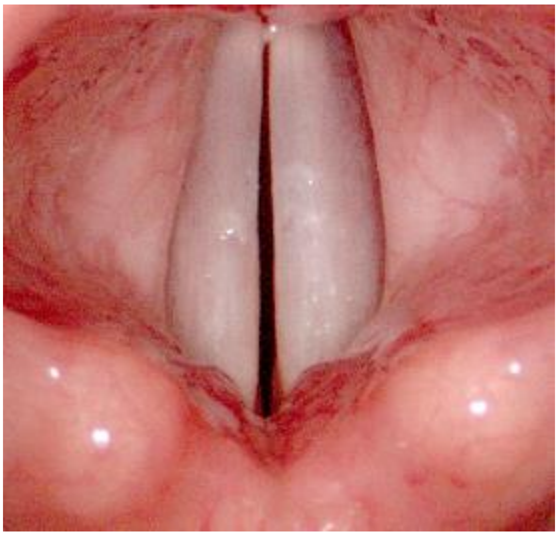
The notes of music are sounds that predominantly have a single frequency. Carnatic music has 7 notes referred to as the *Saptaswara* (7 notes) in Sanskrit. These are *sa, re, ga, ma, pa da, ni, Sa*. These notes span an octave, a frequency ratio of 1:2. That is the frequency of the lowest note (*sa*) is half of that of the highest note (*Sa*). Typical frequency values corresponding to these notes are 240 Hz for the lower 'sa' and 480 Hz for the higher 'Sa.' Similar frequencies are used in Western music also.

Drums produce duller sounds with the vibrational frequencies in the range of about 100 to 200 Hz.

The dull rumble produced by earthquake vibrations is in the range of 0.2 Hz to 20 Hz, which is just below the range of frequencies audible to us.

The frequencies of sounds that we can hear are of much greater range than the frequencies of the speech sounds that we can produce. Men often speak in the range of 65 to 260 Hertz, while women speak in the 100 to 525 Hz range. This brings to the notion of a property of speech (more often used in musical contexts) known as *pitch*. The average frequency of a sound is sometimes referred to as pitch. Thus male voices have a lower pitch than female voices.

This difference between the pitch of male and female voices arises from the difference in the lengths of their respective vocal cords. Male vocal cords are longer in the range of 1.75 cm to 2.5 cm, while female vocal cords are shorter 1.25 cm to 1.75 cm. We will see later how shorter lengths of a vibrating string or a vibrating column produces sounds of higher frequencies.



Human vocal cords

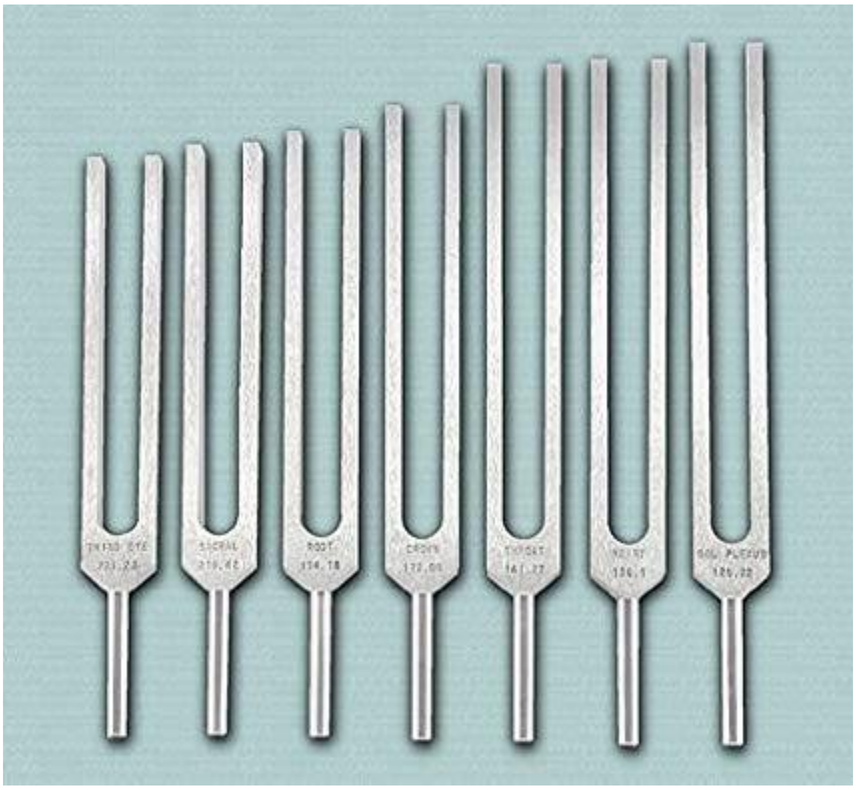
Some gifted individuals – both men and women – are able to overcome this biological limitation and are able to speak and sing both in male and female voices. Listen to this female singer singing a Hindi song quickly alternating between masculine and feminine voices.

https://www.youtube.com/watch?v=OhqfhJhUMQY

Tuning Fork

A standard device used in experiments on sound in a physics laboratory is a tuning fork. It is a basically a Y-shaped piece of metal that can vibrate at a fixed frequency.

By varying the length of the prongs (“arms”) of the tuning fork it is possible to vary the frequency with which it vibrates. Longer tuning forks produce smaller frequencies.



Since vibrations that produce sound are high frequency vibrations, it is hard to see them with the naked eye. But you can see them using special tricks.

The video below shows the vibration of a tuning fork in slow motion.

https://www.youtube.com/watch?v=lxsM9Jv0OD8

This elegant experiment allows you to see the vibrations of sound produced by a speaker.

https://www.youtube.com/watch?v=xasNJBiTLwE

Musical instruments like *veena* or a violin, - the so-called stringed instruments – essentially consist of strings tightly stretch between two fixed ends.

Strings of a veena

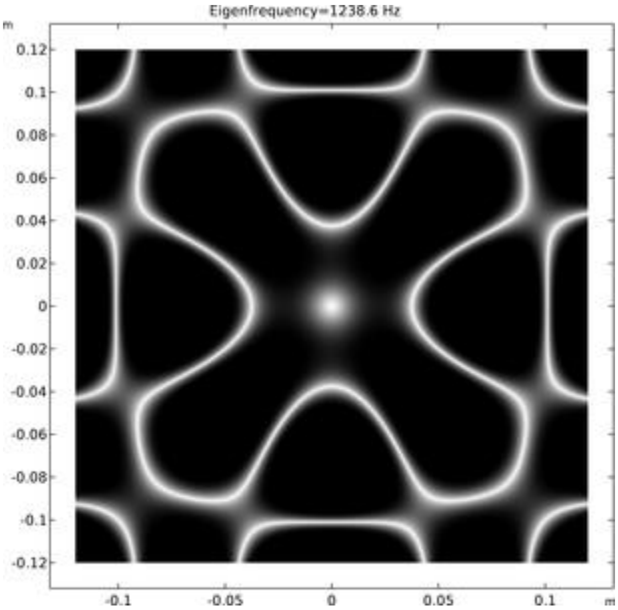
The string when plucked produces sound which is produced by vibrations of the string. It is hard to see these vibrations, the up and down movements of the string, since they are too fast and too small.

But the following video shows the vibrations of a string clearly against a black background. The motor at the left end of the string is vibrating the string at gradually increasing frequencies. The vibratory pattern of the string gradually becomes more and more complex as the frequency increases. For lower frequencies it is quite simple. The string does not move at the ends, since it is fastened, but moves maximally at the center. As the frequency is increased, in the next pattern that emerges, the middle of the string also is stationary and you see maximum motion at two points on both sides of the stationary mid-point.

https://www.youtube.com/watch?v=BSIw5SgUirg

In the experiment describe a little while ago, you have seen the surface of water vibrating in response to the vibrations of the surface of the speaker below.

We now directly see the vibrations of a surface. This experiment involves a flat metal plate that is painted black. White powder is randomly sprinkled all over the plate. Then a motor connected to the plate vibrates it. You will see the white powder dancing around and settling down in beautiful stable patterns. Basically when the plate vibrates, there are points on it that move up and down and points that do not. The white powder collects at those points where the plate does not move up and down. The patterns thus produced enable us to visualize sound. They are called Chladni's patterns.



A Chladni pattern

The video below shows the experimental setup for producing Chladni patterns.

https://www.youtube.com/watch?v=wvJAgrUBF4w

These patterns are named after German physicist and musician Ernst Chladini who performed extensive studies on vibrating plates.

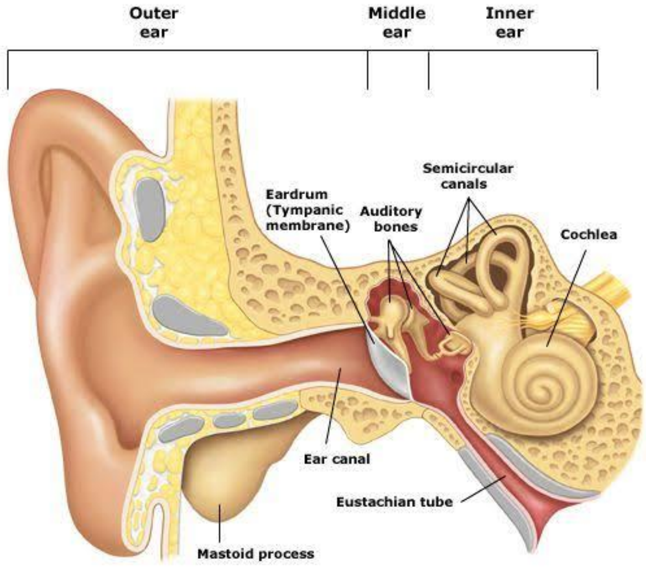
4. Amplitude and loudness:

Make a toy bow with a bamboo strip and a plastic rope. Make sure the rope is sufficiently taut. Now gently pull the string and let go. It produces a "twang" which can be audible. It is clearly produced by the vibrations of the rope. Now pull the rope harder – you will hear a louder twang than before.

In this case you will notice that the to-and-fro motion of the rope is greater than in the previous case. This span of the two-and-fro motion of a vibrating object is called *amplitude*.

The greater the amplitude of the vibration, the louder the sound gets.

Sounds are nothing but fluctuations in air pressure produced by a source of sound. These fluctuations in air pressure produce corresponding vibrations in a sensitive membrane called the eardrum located inside our ears. Just as our skin can sense touch, the ear drum senses changes in air pressure. The louder the sound, the greater is the fluctuation (or amplitude) of the air pressure.



Eardrum is seen in the picture above.

Intensity is a scientific term for “loudness” of sound.

Although the ear drum is quite delicate it is capable of sensing a wide range of loudness. The ratio of the sound intensity that causes permanent damage to the ear drum to the sound intensity that is barely perceptible is 1 trillion (i.e. 1,000,000,000,000). Since such large numbers are difficult to understand, scientists use a more convenient scale that expresses this ratio in terms of logarithms. According to this measure a 10 times increase in the ratio only increases this measure by a value of 20. A 100 times increase in the ratio only increases this measure by 40, and so on.

Such a measure is called a Decibel. The ‘bel’ part of this word comes from the name of Alexander Graham Bell in honor of his pioneering contributions to telephony. The ‘deci’ part which means 10, refers to the fact that a 10 times increase in ratio is taken as a standard “step” in defining this measure.

Decibels is often used in short form as dB.

Normal human speech has intensity of about 60 dB. A decibel level of 85 dB is considered to be threshold beyond which sounds are not safe for human ears. Automobile horns have a dB of about 115. Therefore, honking must be treated as an aggression on our auditory systems. The siren of an ambulance, which is deliberately made to be extraordinarily loud, has an intensity of about 120 dB.

5. Sound needs a medium to spread:

We have seen that sound originates from a vibration, from the back and forth motion of a piece of matter at a given point. From there it spreads around, reaching points near and far.

How does sound travel from one point to another?

First of all, we know from daily experience that sound must travel. That's the reason why we hear voices of people talking in another room or the booming sound of a supersonic jet far away in the sky. The original vibration creates a disturbance in the surrounding air, which travels through the air reaching points far and near.

By corollary we must understand that sound cannot travel in vacuum. Or if there is a partial vacuum sound does not travel effectively or diminishes in intensity. Let us do a small experiment to show this.

For this experiment we need a large bell jar, a mobile phone, a large plate and a candle. Place the plate on the table and pour a little water in it. Place a raised platform in the water and place the mobile and the candle on the raised platform. Make sure the ringer of the mobile is on. Now light up the candle and cover the mobile and the candle with the bell jar. Call the mobile now. You can hear the sound coming from inside the bell jar. Now the burning candle begins to consume the oxygen present inside the bell jar creating a partial vacuum. As this process happens, you can hear the sound coming from inside the bell jar slowly diminishing.

In a well-equipped physics laboratory you will find apparatus with which you can produce near perfect vacuum. Sounds produced by a speaker placed inside such a vacuum chamber are almost completely dampened as demonstrated in the following video.

https://www.youtube.com/watch?v=Oyq8Di01nN8

Fun fact:

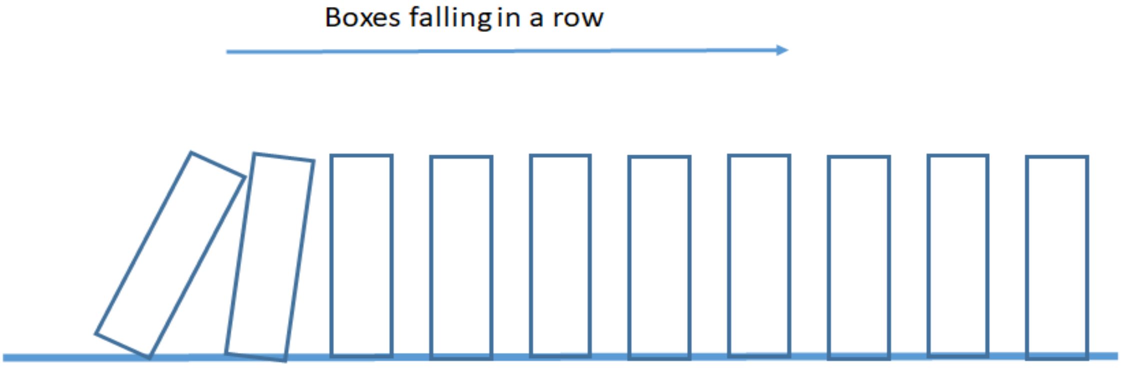
In deep space, there is a near total vacuum. The density of matter is so low in space that you will hardly find a single atom in a volume of a cubic centimeter. Therefore, astronauts communicating in deep space, or on an airless world like the Moon, must use radio signals for communication. They cannot shout out to each other!

a. Propagation of sound through media – an analogy

The manner in which sounds propagate through matter can be understood using a simple familiar analogy.

In our country we are used to standing in long queues – at temples, movie theatres and so on. When the queue is sluggish, some restless person pushes the person in front of him/her. This other person helplessly falls on the person in front of him/her. This “influence” propagates sometimes over considerable distances. You will know this when you hear an angry bark from the front of the line: “Hey! Don’t push!”

The above scene can be recreated in a simple experiment. For this experiment, you will need a set of identical cuboidal wooden blocks. Or a simpler solution is to lay your hands on a bunch of empty cigarette boxes or match boxes. Place the boxes in a row as shown in the figure below. Now gently tap the box at on one end so that it falls on the box next to it. When nudged by the first box, the second box falls on the third box. The process continues as all the erect boxes fall in an orderly fashion, one after the other.



The above scene is a convenient analogy of how sound propagates through matter. The initial disturbance or vibration which is the origin of the sound "pushes" or displaces some atoms in the material. These atoms or molecules move forward and "push" a few other atoms. Thus the initial "push" of the original vibration propagates along the material over some distance. In the above process, note that each atom moves only a small distance until it strikes the next atom. After the collision, the second atom moves forward while the original atom bounces back. This process is repeated by a series of atoms each transferring its energy and motion to the one next to it.

Dominoes and sound traveling through solids, liquids and gases

https://www.youtube.com/watch?v=BYe4x3x35is

You can also compare the above process with a familiar scene that you witness often at construction sites. A row of individuals, each standing nearly arm's length apart transfer bricks from a pile to a construction site. In this case the individuals do not move: only the bricks keep changing hands in an orderly fashion, moving forward.

b. Propagation of sounds through solids:

Sounds can travel through solids too, in fact better than through air. There is a simple experiment which almost every kid performs at some point or other to prove to herself or himself that sound propagates through solids.

The experiment is called a cup telephone. You can make a pretty amazing telephone using two cups (paper or plastic cups), a piece of thread and two match sticks. Make a hole through the bottom of one of the cups and pass one end of the string through it. Tie one of the match sticks to the thread sticking out of the cup. Now repeat the exercise with the other cup, using the other end of the thread and the second match stick. Make sure the string is sufficiently long – say 5 to 10 meters. You can ask a friend or a sibling to hold one of the cups and stand as far as the thread permits. Now speak at your normal voice into your cup. Your friend/sibling should be able to hear what you are saying pretty comfortably. Use a slightly thicker string for superior results.

In this case the vibrations produced by your voice propagate along the string and reach the other end of the string.

Another familiar example of a device whose function depends on sounds propagating through solids is the stethoscope that you might have seen when you visit a doctors' clinic. You cannot hear the heartbeat of another person, - or for that matter your own heartbeat – using your unaided ears. The far end of the stethoscope has a bell-like hollow structure covered by a rubber sheet called the 'diaphragm.' The near end of the stethoscope is split into two earpieces which the doctor places in her/his ears. When the doctor gently presses the diaphragm on your chest over the left side (rarely in some people, right side), she/he can clearly hear the lub-dub sounds of your heart.

Stethoscope

With a device similar to a stethoscope, known as the fetoscope, doctors can even listen the heartbeat of a fetus in a mother's womb. It consists of a large conical tube. By pressing it on a mummy's tummy, the doctor will be able to listen the feeble heartbeat of a fetus.

The fact that sound propagates well through solids can save lives in some special situations. Imagine you have to cross a railway bridge. The railway track bends around an obstacle like a hill, for example, on the other side of the bridge. Therefore, you cannot see a train coming from the other side. How do you decide whether to cross the bridge?

The simple solution is to set your ear down on the track and listen for vibrations. If the train is even a few kilometers away, you can hear the vibrations clearly by setting your ear on the railway track. (Do not do these experiments without adult supervision!)

The Native Indians of North America are said to have the ability to hold their ear to the ground and listen for sounds of hooves of horses coming from a distance. Of course, this skill may perhaps be exaggerated and dramatized in some old Hollywood films.

It is because sounds or vibrations propagate through solids so well, it is possible to pick up the vibrations of an earthquake over great distances. Earthquakes can be felt by humans even as far as 500 km. Using sensitive electronic devices, it is even possible to sense earthquakes that occurred on the other side of the earth.

The study of sound vibrations that propagate through the body of the earth is called Seismics.

Bone conduction

Normal hearing occurs when sound vibration propagating through the air impinge on a membrane called tympanum (“ear drum”) and vibrates it. These vibrations are passed on to a delicate chain of bones in the inner ear. But in deaf people when this machinery is damaged, it is possible to listen to sounds by bypassing this system completely. Sounds can propagate through the body – which is a solid – and more particularly in bone since it is the densest part of the body. There is a special kind of hearing aid in which a vibrating device directly communicates its vibrations to the bone of the skull which can be heard by the listener quite clearly. In more dramatic demonstrations of this technology the vibrations can be communicated to the bone of the elbow (since there is only a very thin covering of the skin over the bone near the elbows) and listener can hear the sound quite clearly.

Such bone conduction-based hearing aids are sometimes used by the military. These hearing aids only come into contact with the bone behind the ear and leave the ear uncovered. Therefore, the soldier who is wearing the hearing aid can hear the normal sounds coming from the immediate surroundings and also the sounds coming through the communication devices from another soldier who is at a distance.

See this video for a demonstration of bone conduction.

https://www.youtube.com/watch?v=QIaX8EpNfsQ

c. Propagation of sounds through liquids:

Sounds can propagate through liquids too, better than it does in the air.

To verify the above you can perform a simple experiment in a most un-laboratory-like premises, in your bathroom! For this purpose, you need a bathtub. Fill the bathtub with water. Then shut your eyes and ask your friend to strike two spoons together inside the water. Can you hear the sound? Probably not. Now dip your head in the water (make sure you stop breathing!) and ask your friend to strike the spoons. This time you can hear the clinking sound of the spoons much more loudly than before. This is because sound travels more effectively in liquids than in the air. In the first case, though the sound was produced inside water, it had to propagate through air to reach your ears. In the second case, it had to merely propagate through water to reach your ears.

Whales take this important acoustic property of water to communicate over long distances. Like certain birds, whales also sing songs to other whales. Some songs are remarkably long, lasting as long as 30 minutes. The songs of a humpback whale can be heard by other humpback whales almost 100 miles away.

Sounds are not only louder in liquids and solids compared to air; they travel faster too. The table below lists the velocities of sound in certain materials.

	Material	Velocity (m/s)
Solids		
	Steel	5790
	Iron	5950
	Brick	3650
	Wood	3850
Liquids		
	Sea water	1531
	Mercury	1450
Gases		
	Air	343
	Nitrogen	334
	Oxygen	316
	Argon	319

These differences in velocity of propagation of sound in solids, liquids and gases can be understood by a simple intuitive demonstration.

Let us repeat the ‘row of boxes’ experiment we performed in the section 5a “Propagation of sound through media – an analogy.” This time we perform the experiment under three conditions, corresponding to solids, liquids and gases respectively. We know that typically solids are denser than liquids which in turn are denser than gases. Therefore, in solids the atoms are packed quite closely; the distances between atoms are short. In case of liquids, the interatomic distances are slightly longer than in solids. Gases have the least density – so the atoms are spaced wide apart. Let us arrange the boxes in our experiment to reflect the distributions of atoms in the three cases – solids, liquids and gases. The boxes are more closely arranged in the first experiment corresponding to solids. The spacing is slightly longer in the second case corresponding to liquids and even longer in cases of gases.

For the first case of “solids”, when you tap on the first box, it quickly falls on the second box since it is quite close. Therefore, the disturbance propagates quite rapidly along the row of boxes.

In the second case of “liquids,” since the inter-box distance is slightly longer, it takes slightly longer for one box to fall on the following box. So the disturbance propagates a bit more slowly than the previous case.

In the third case of “gases”, since the spacing is the longest, the disturbance takes the longest time.

The above demonstration gives an insight into the connection between the distance between atoms and the velocity of propagation of sound.

6. Sound propagation through confined spaces

Above we stated that sound propagates faster through solids and liquids than in the air. We also stated that sound can be heard louder in solids and liquids than in the air. While the speed of sound depends essentially on the material, loudness depends on factors other than the type of the material. It also depends on the shape of the material.

Sound can propagate in an open medium without any barriers that constrain the path of propagation of sound. The analogy to this is people moving unconstrained in an open field. They can move in any direction without any restriction. Or sound can propagate in confined medium with barriers that shape the propagation of sound. The analogy to this is people walking on the roads, or moving between barricades as they move in a queue.

As an example, let us revisit our favorite cup telephone. We have already convinced ourselves, if you and your friend stand at about 20 meters apart, and if you speak in a normal voice, it is difficult for your friend to make out what you are saying. But if you speak through the cup at your end, and if your friend is listening through the cup at the other end, you voice will be quite audible. This is because in the first case sound propagates through the open air in an unconstrained fashion. In the second case sound propagates along the string, confined to the length of the string. Two factors ensure that the sound is heard louder with the cup telephone. One of them is the factor we already know - the fact that sound is propagating through solid matter of the string. The second reason the sound is louder with the cup telephone is that the sound is confined to the string.

Why is the sound louder when it is confined to the string?

Let us compare the situation when the sound propagates through an open medium with the situation when it is confined to a string.

Consider the situation when you are standing in the middle of an open space and shouting. The sound energy you produce propagates in all directions. Consider an imaginary sphere of radius R meters centered on you. The sound energy you produced flows in all directions and crosses the spherical surface. Since the surface area of a sphere is $4 \pi R^2$, if your friend is standing at a distance R, and if his/her ear is of area A, the fraction of sound energy that enters your friend's ear is $A/(4 \pi R^2)$. Now if your friend moves further away to a distance twice (= 2R) the original distance, the fraction of energy received is going to be $A/(4\pi(2R)^2) = A/(16 \pi R^2)$. Thus the sound energy received at a distance 2R is only 1/4th of the energy received at a distance R. Similarly, if the distance increases to 3R, sound energy received will be only 1/9th. The sound energy is the same as loudness of the sound. Therefore, as distance increases, loudness falls as "inverse square" when sound propagates in an open space.

In case of the cup telephone, sound is confined to the string and therefore does not follow the "inverse square" law. Sound in this case is channeled through the string and is not freely dissipated into the surrounding space. However, in this case too loudness diminishes with distance but it happens more slowly.

For the above reason, the cup telephone gives good results even if you use a thin hollow air-filled pipe, instead of a string. That must be at a first glance surprising because in this case the material is mostly air that is surrounded by solid material. The telephone works even with a hollow pipe because in this case too, sound propagates through the confined space of the pipe and is not freely dissipated in the surrounding air.

The same principle applies even in case of a stethoscope. Earlier we said that a stethoscope works because of the solid tube that constitutes the stethoscope. Actually it is not quite true. It is not a solid tube but a hollow pipe. The sound can be heard loud and clear because it propagates securely through the pipe.

When you are yelling out to someone at a distance, you tend to cup your hands around your mouth. This arrangement essentially tends to shape the flow of the sound energy allowing it to flow in the "forward" direction at least up to the point it reaches the edges of our hands. By this step, you are preventing the spreading of sound in all direction and channeling it slightly in a single direction.

The same principle is exploited in the design of loud speaker cones which look like much larger, and more sophisticated version of your cupped hands. In this case too, the flow of sound energy is channelized by the walls of the conical loud speaker.

Another interesting example of sounds in confined spaces are echoes. The next time you go hiking on a mountain, if you are in a space surrounded by hills, holler to the hills. You will hear the hills hollering back to you in the form of echoes! If you shout "hello", you will hear a series of hellos each fainter than the previous one. When that happens your original “hello” bounces off the hill in front of you, returns to the hill on which you are standing, bounces again to travel back to the hill in front of you, and so on. Every time these reflections come back to you, you hear an echo of your hello.

A familiar analogy to the above phenomenon is what happens in a carom board when you hit a striker hard so that hits the wall in front of you head on. The striker bounces back and forth between the two opposite walls, before it stops somewhere in the middle after it had expended all its energy.

6.1 Buildings as Confined spaces:

Buildings are confined spaces that provide us with comfort, privacy and protection. The confined spaces of a building channelize propagation of sounds in interesting ways. There is an entire science dedicated to the study of how sounds bounce off the walls of a building. It is called *architectural acoustics*.

There are examples of brilliant acoustics among some of the ancient monuments of the world. One noteworthy example is the Golconda fortress in Hyderabad. Even as you enter the fort there is an open portico with a curved ceiling. If you stand right under the center of the pavilion you will be startled by a loud clatter of echoes produced by the ceiling. The echoes produced are so loud that they be heard at the citadel at the top of the hill more than a kilometer away.

https://www.youtube.com/watch?v=F9unuG8zBFs

In the country of Estonia, in a place called Voru, architects have created this larger than life version of a loudspeaker cone. This giant wooden structure has a small mouth at one end gradually expanding towards a large opening at the other. This “loudspeaker” is meant to be a mouthpiece, not of mortal humans, but for the woods themselves! It is meant to amplify the natural sounds of the flora and fauna of the forest.

Buildings with hemispherical, or ellipsoidal enclosures have an eerie acoustic property. They can amplify whispers uttered at one wall allowing them to be heard at a far off wall. They are called Whispering Galleries.

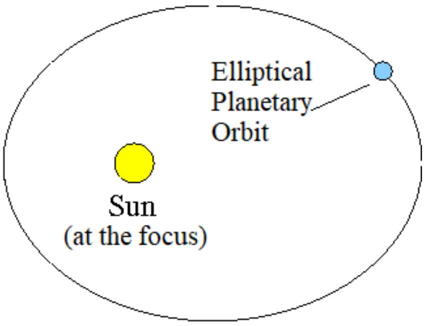
This is because the ellipse has an interesting geometric property. An ellipse basically looks like a circle stretched in one direction. There is an easy way to draw an ellipse using a string, two pins and a pencil.

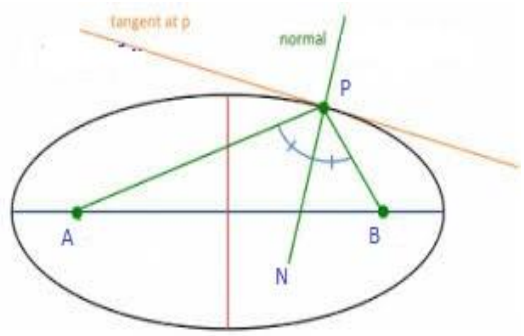
Stick the pins on a drawing board at a suitable distance. Tie the two ends of the string making it a loop. Make sure the loop fits over the two pins leaving some slack. Now place the pencil at any point on the inner side of the loop and pull outwards gently so that the pencil and the two pins form a triangle with the string forming the perimeter of the triangle. Now move the pencil around keeping the string taut at every point. The curve traced by the pencil is an ellipse.

This video demonstrates above the procedure:

https://www.youtube.com/watch?v=Et3OdzEGX_w

It is remarkable that the path following by the planets around the sun is also an ellipse with the sun at one of the foci.





In the elliptical figure the locations of the two pins are called the foci of the ellipse. The importance of (the position of) these points (let us call them A and B) in the ellipse can be brought about by connecting them to any point P on the ellipse. Draw a line that cuts the ellipse at P exactly perpendicularly. Let us call this line PN. You will now notice that the angle made by the line AP with the perpendicular is exactly the same as the angle made by the line BP with PN. This will be true no matter where you pick the point P. Why is this interesting?

Think of the ellipse as a physical reflecting surface (like a mirror) which you are observing from above. Think of the line AP as a ray of light originating from A and falling on that surface at P. The ray bounces off the surface and travels in a different direction. We know from the law of reflection of light that the angle of incidence is the same as angle of reflection. That is exactly what is happening inside the ellipse above. Therefore, if you project a ray of light standing at A inside the ellipse so that it falls on the elliptical wall, no matter where it falls on the wall (at point P), the reflected light always comes back and goes through the other focus B. All rays of light that originate from A, reflect on the elliptical wall and return through B!

Now coming back to our example of acoustics, just light rays of light, sound waves also follow the same law of reflection. If there is a elliptical wall, and if you stand at A and shout, all the reflected sounds go through B. Even in a large elliptical hall, if speak softly at A, another person standing at B can clearly hear what you are saying. This is the principle behind whispering galleries.

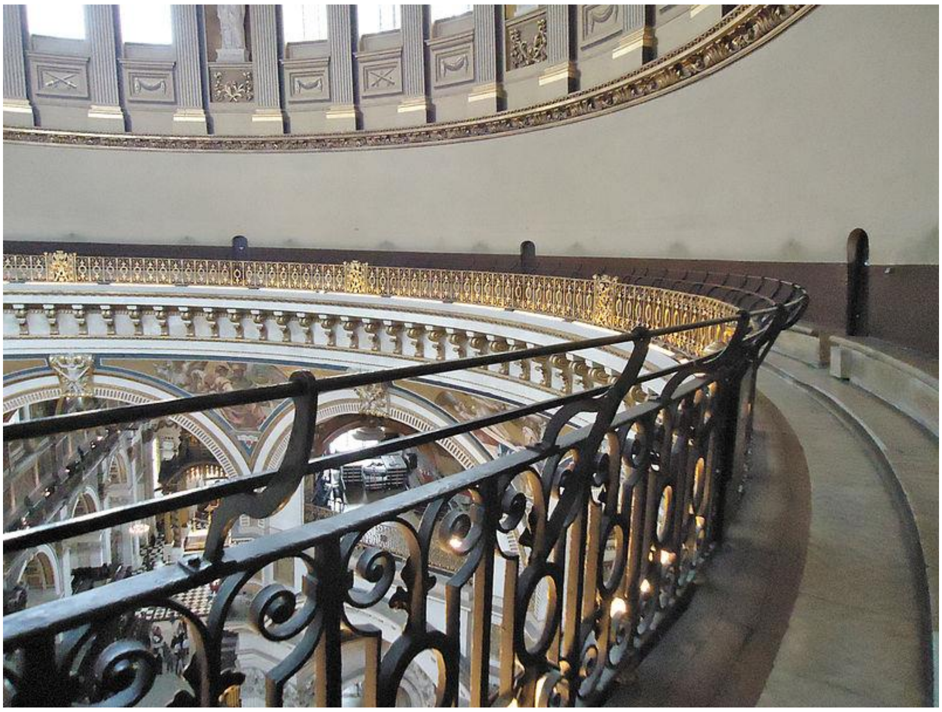
The only difference from the above description is that instead of an elliptical wall, they have an elliptical ceiling.

There are such whispering chambers for example in the Golconda fort. If you stand near one of the corners, turn towards the wall and speak in a low tone, you friend standing at the opposite corner can hear you quite clearly.

Another example is the Gol Gumbaz mausoleum in Bijapur, Karnataka. Its special acoustics derive from the hemispherical shape of its ceiling. Even a soft whisper spoken near one wall can be heard at the opposite point of the wall.

Gol Gumbaz Mausoleum of Bijapur

Another example of such whispering gallery is St Paul’s Cathedral in London.



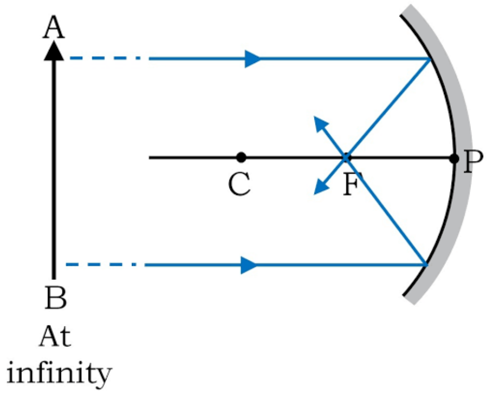
St. Paul’s Cathedral, London

We can extend the mirror analogy and account for another interesting acoustic phenomenon observed in real world structures.

We know that, in concave mirrors light coming from infinity is concentrated at the focal point. For this reason, concave mirrors are used to concentrate sunlight and produce heating effects.

Concave Mirror -

Object at infinity



By the same line of reasoning, we can easily imagine how a large concave surface can concentrate *sounds*.

Concave acoustic mirrors were being used by Royal Air Force of the United Kingdom during World War – I to detect incoming enemy aircraft from a great distance. Figure below shows one such mirror that is 4.5 meters high located in East Yorkshire of UK. At the focal point of the mirror there is a microphone mounted on a vertical pipe. Sounds detected and amplified by the mirror are picked up by the microphone and sent to the control station. Such acoustic mirrors were being used before the invention of radar.

Acoustic mirror located in East Yorkshire, UK.

Knowingly or unknowingly we use the principle of an acoustic mirror quite often in our day-to-day life. When we struggle the understand the words of someone who is speaking too softly, we instinctively form a cup with our hands and place it behind our ears in an attempt to form an acoustic mirror and amplify the feeble sounds.

6.2 Suppressing echoes

While some buildings are specifically built to amplify faintest sounds and generate a rich auditory tapestry of echoes, that may not be the objective of all architectural creation. A lecture hall or a concert hall or a recording room in which every stray sound is amplified will become completely useless.

There are some surfaces that reflect sounds well and then there are others that absorb sounds. If a building has sound reflecting walls it creates a lot of echoes. When you speak loudly in such a building, it is as though the walls of the building play back to you the words you spoke, but after a delay. And this play back is not just a one off event, because the sounds repeatedly bounce off opposite walls – like a striker bouncing repeatedly between opposite walls of a carom board.

Generally, rooms with high ceiling, or walls made of stone or glass tend to reflect sounds and produce echoes. Interior designers use several techniques to suppress disturbing echoes in the building. One basic strategy is to create soft or rough surfaces. Soft surfaces absorb the sounds while rough surfaces scatter the sounds in all directions dissipating their energy. There are several innovative ways of achieving this.

Hang large canvas paintings of textile paintings on opposite walls.

Place a large book case against the wall. Books replace the hard walls with a softer and rugged surface.

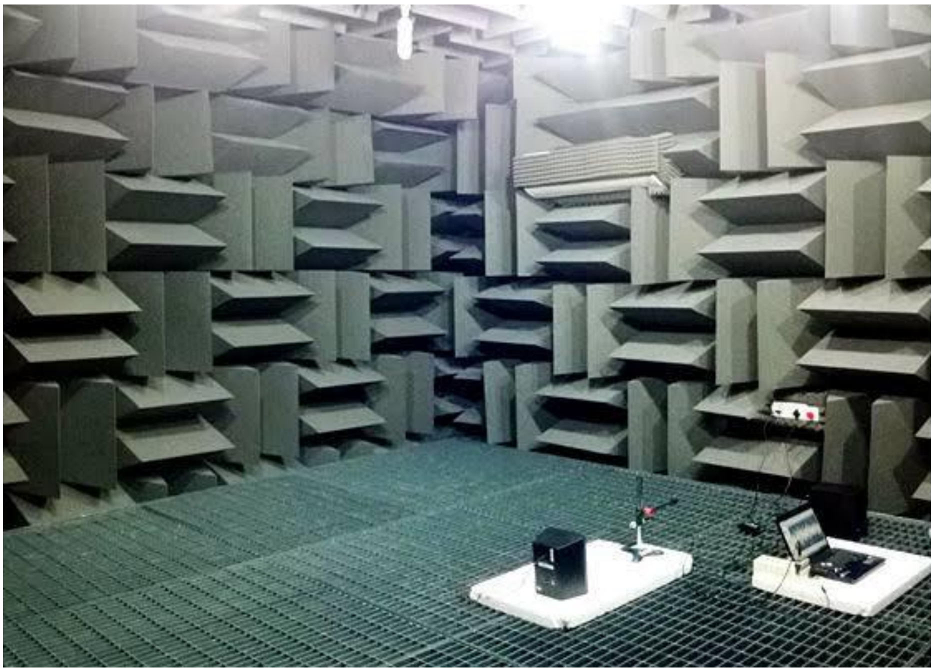
Use rugs or carpets on the bare, hard floors.

There are special acoustic panels with which walls can be covered so as to suppress echoes. These panels are regularly serrated surfaces which scatter the sounds impinging on the walls.

Acoustic panel

Creating rooms with little or no echoing is an art. Such rooms are necessary for recording music or speeches of high quality with no noise. Such rooms called 'anechoic chambers' will be found typically in radio stations or music companies.

The walls of an anechoic chamber will almost completely absorb the sounds impinging on them. So in such a room it practically feels as though the room has no walls, as though the room is infinite in size.



Anechoic chamber

6.3. Sounds in Confined Spaces: Musical instruments

The idea of sound propagating through confined spaces brings us to a very important property shared by most sound producing devices. That property is known as *resonance*.

To understand the concept of resonance we must first understand the concept of natural frequency.

Let us take the example of a swing we visited in Section 3. If you give a swing a shove and disturb it from its resting position, it swings back and forth a few times and comes to standstill, until you push it again. The frequency at which it swings is a property of the swing. Even you push it harder, its amplitude increases, i.e. the extent by which it swings to a side increases, but the frequency will be nearly the same. That frequency is the natural frequency of the swing.

The same thing is true of a simple pendulum whose natural frequency depends on the length of the string by which it is suspended. The longer the length, the lower is the frequency.

Or consider a mass suspended from a spring. If you now disturb it from its resting position, you will see the mass go up and down a few times before coming back to rest. The frequency at which it oscillates depends on the mass and a property of the spring called the spring constant.

Another example is the tuning fork which vibrates at its own frequency. Here too the longer the arms of the turning fork, the lower is its frequency of vibration.

Another fun example is a rubber duck that children play with in a bathtub. Consider a rubber duck floating in the still water of the tub. Here too if you gently disturb it, - it will not work if you make a big splash, - it bobs up and down at a particular frequency.

Therefore, there are many instances in which a system oscillates or vibrates at a characteristic frequency called its *natural frequency*.

Another interesting example of a system with its own natural frequency is an air filled chamber with a narrow mouth. Something as simple as that can have its own frequency as we shall see by probing it in a certain way.

Consider a jar with a narrow mouth. If you gently and briefly blow into it, you will be momentarily compressing the air inside the jar. This compression creates the extra space necessary to accommodate the extra air that you forced into the jar. But the initial compression is followed by a decompression, which pushes the extra air out of the jar. This creates a low pressure (lower than the pressure of air outside) inside the chamber. Therefore, air outside rushes into the chamber again creating another high pressure situation. Thus your initial disturbance of the air pressure caused by blowing, produces an oscillation or vibration of the pressure in the chamber. The nature of this oscillation is not very different from that of the examples we just saw above. The frequency of this oscillation is the natural frequency of the jar.

If the natural oscillation of an air chamber like the above falls within the audible range of frequencies (20 Hz to 20,000 Hz) you will actually hear the sounds produced by the chamber. In fact, this is the underlying principle of a wide range of musical instruments.

Perhaps the simplest “musical instrument” with an air chamber, with which you can test the above idea is the humble pen cap! In fact, probably you are already familiar with the idea of blowing into a pen cap to make music. Of course, caps of ball pens may not work because they are often too short and shallow. The cap of an ink pen that is about 5 cms long would be ideal. If you held it vertically below your lips and gently blow into it – as you would into a flute – it makes a fairly pleasant sound. It will produce only a single note whose frequency depends on its length. The longer the length, the lower is the frequency of the note produced.

In fact, the flute also works on the same principle. A flute is basically an air chamber that is cylindrical in shape. Since the note produced depends on the length of the air chamber, the flute has provision to change the length of the air chamber by shutting the holes on it with fingers.

In an Indian flute shown in the figure below, there is a hole on the side into which the flutist blows. A little distance away from that hole there are 7 holes. If you leave the hole closest to the blowing hole open, the length of the air chamber is the shortest. Shrill notes are produced in this way.

If you shut all the holes the length is the longest. Notes of lower frequencies are produced this way.

Another remarkable musical instrument that is also based on use of air chambers of different lengths is a *Jal Tarangini*. In this instrument there are metal (or ceramic) cups partially filled with water to various levels. The air chamber in this case is the part of the cup that is unfilled by water, or filled by air. When the edge of the cups is gently struck by a metal rod or a wooden stick it produces a delightful note.

But in case of Jal Tarangini we must note that it is not just the vibrations of the air chamber that contributes to the music. The vibrations set up inside the cup itself contribute prominently to the sweetness of the sound.

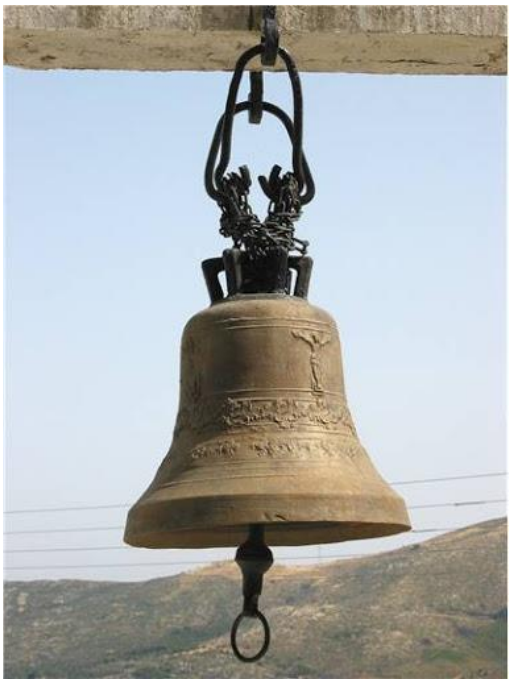
Here is a video of a master musician playing on the Jal Tarangini.

https://www.youtube.com/watch?v=TwzYjNR7uiA

Another simple, domestic example of an air chamber producing loud sound is a bicycle bell, which consists of a hemispherical steel cap enveloping an air chamber. When you press the lever that sticks out of the bell, a gong strikes the cap from inside, producing vibrations. These are vibrations not just of the air inside the chamber, but of the steel chamber itself. You can easily test this fact. Just place the palm of your hand on the bell and gently press it. The sound disappears in a moment. This is because when you press the hand on the bell, the softness of your palm absorbs the vibrations of the cap and kills the sound.

Bicycle bell

Vibrations of the material of the instrument are even more prominent in case of a large bell. Like a tuning fork that vibrates and produces sound long after it is struck, a struck bell continues to produce sound long after it is struck. In case of a tuning fork, the vibration consists of two and fro motions of its arms, as they move closer and farther away from each other. The vibrations of a bell, however, are a lot more complex. You can feel the vibrations of the bell simply by placing a hand on it.



Another quaint musical instrument similar to a bell in operation, but does not look like a musical instrument at all, is the Tibetan singing bowl. It is basically a bowl made of bronze or sometimes of cast iron. When struck by a wooden stick called a mallet, it produces a sweet sustained note at a unique frequency. The exact frequency of the note depends on the size of the bowl and its material. Even a small bowl, about 10 centimeters in diameter, when struck, produces a note that lasts about 10 seconds long. The soothing sounds produced by the singing bowls are used by Tibetan monks for meditation.

A Tibetan singing bowl

We can also consider the example of stringed instruments like a veena, violin or a guitar. Stringed instruments have, in addition to a vibrating air chamber, a vibrating string. You will see multiple strings tautly fixed between two ends. We have briefly visited a vibrating string above in Section 3. There is an interesting similarity between the vibrations of an air column and that of a string. Just as longer air columns produce lower frequencies, longer strings also produce lower frequencies.

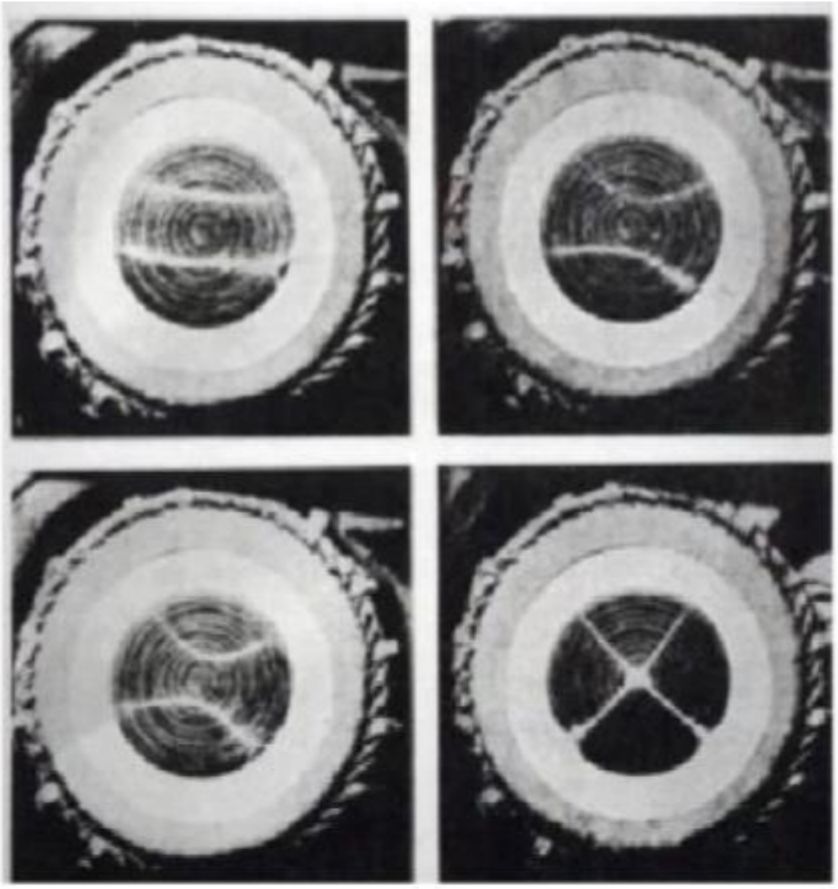
We have seen how, in a flute, the flutist produces different notes by closing holes with fingers, effectively varying the length of the air column. Likewise, in a stringed instrument the musician effectively changes the length of the string by pressing the string down at various points.

Therefore, you will see a combination of two key components in most musical instruments. The first is a source of initial vibration – like the strings in a violin or a wooden rod in a Jal Tarang. The second is an air chamber or an air filled cavity, of specific shape, the walls of which are made of special material – like the hollow chamber in a violin or a cup in a Jal Tarang. The sound produced by the first component is given a longer lease of life by the second.

Fun fact:

You probably have heard of Prof CV Raman who was the first Indian to get a Nobel prize in Physics. But do you know that Prof Raman had done extensive work on the acoustics of Indian musical instruments?

Picture below shows the vibratory patterns of an Indian drum called Tabla revealed by sand trails on the surface of the tabla. The photograph is from a paper titled “Indian musical instruments” written by Prof Raman in 1935. Note that these patterns are similar to the Chladni patterns we have seen earlier.



Vibratory patterns of a Tabla

6.4 Resonance:

In this section we shall see an important idea: confined spaces can produce vibrations that persist for an unusually long time at a characteristic frequency. This frequency is called the resonant frequency of that system.

A key feature of resonance is that an object that can produce sound at a unique frequency also has the property of strongly responding to a sound exactly at that very same frequency.

Resonance is typically demonstrated using a combination of a tuning fork and an air column. We have seen already that a tuning fork vibrates at its own characteristic frequency. Likewise, an air column also vibrates at its own frequency. What happens when you bring a tuning fork vibrating at frequency, f_{tf}, to the mouth of an air column whose characteristic frequency is f_{ac}? It depends on the relationship between f_{tf} and f_{ac}. If the two frequencies are about the same, the air column responds by producing a loud sound. If not there is no response from the air column. In other words, when the two frequencies match ($f_{tf} = f_{ac}$) the air column resonates to the tuning fork. When that happens the two objects (in this case the tuning fork and the air column) are said to satisfy the resonant condition.

This phenomenon is demonstrated in the following video.

https://www.youtube.com/watch?v=LmNUsZBAoYM

In resonance phenomenon, one object acts as a source of sound, and the other as a receiver of sound. Basically, the receiver can respond well to the sounds coming from the source of sound, when the two are in a resonant condition. In reality, a resonating object responds not just to a unique frequency, but a small range of frequencies or a frequency band. It can respond to any frequency within that range but not beyond.

This is a property seen in any receiver of sound, like for example a microphone or a “mike”. When you speak or sing into a microphone or a mike, a membrane inside the mike responds to your sounds. These vibrations are converted into electrical signals by a circuit present inside the microphone. For the mike to respond to your speech sounds or sounds of your singing, it should respond to the full range of frequencies that your vocal cords can produce. Human vocal cords can produce sounds or vibrations in the range of 100 – 1000 Hz. But a good microphone responds to a much greater range of frequencies, like for example 100 Hz to 10,000 Hz. Likewise, even the human ear can respond to a wide range of sounds – from 20 Hz to 20,000 Hz – much greater than the range of frequencies that can be produced by the vocal cords. Why is it so? Because the human ears need to hear and comprehend not just the vocal sounds of other people, but a wide variety of sounds produced in the world around them.

7. Sound waves:

We spoke of a source of sound as something that vibrates. We spoke of a receiver of sound as something that can resonate to that sound, at a certain frequency or a band of frequencies. But how does the sound travel from the source to the receiver? We said earlier that sound propagates through a material medium (gas, liquid or solid). But how exactly does it get from the source to the receiver traveling through a medium?

A Water Wave:

To answer the above question, let us perform a simple experiment. Let us take a rectangular tray (in which we normally place files and papers) and fill it with some water about 1 inch deep. Let the water settle down until the surface becomes totally still. Then gently lift one end of the tray slightly (by about a couple of inches) and set it down again. You would have succeeded in producing a beautiful wave that travels from one end of the tray to the other, bouncing off at that end, returning back to where it started, and repeating this process for a few cycles before it completely dies down. You can even find the speed at which the wave travels, if you want to, by measuring the length (L) of the tray, and the time (T) taken by the wave to go from one end to the other (using a stop watch) and calculating,

Speed = Length (L)/Time (T)

in the above experiment, you see the wave traveling across the length of the tray, but the water underneath does not move much. How is it possible? Let us do a small experiment, which is actually a fun game, to understand the above.

A People Wave:

Collect a bunch of your friends and sit in a single long row on a long bench. (If you don’t have a single long bench, connect several shorter benches and form a long bench!) Now in this game, each kid (assuming you are one!) must repeatedly stand up and sit back. The only thing is, this cyclical standing and sitting must be done in a sequence. First, the leftmost kid stands up and quickly sits. From then on each kid must wait until the kid next to him begins to move, and then get up himself/herself after a short delay.

When you play the above game, you will see a “wave” starting at the left end and propagating to the right end. Although you see a propagating “wave” you know well that none of the kids is actually running along the “wave.” Each kid is at the same location moving up and down. But their motions are synchronized in a certain fashion, thereby creating a wave that moves in a specific direction.

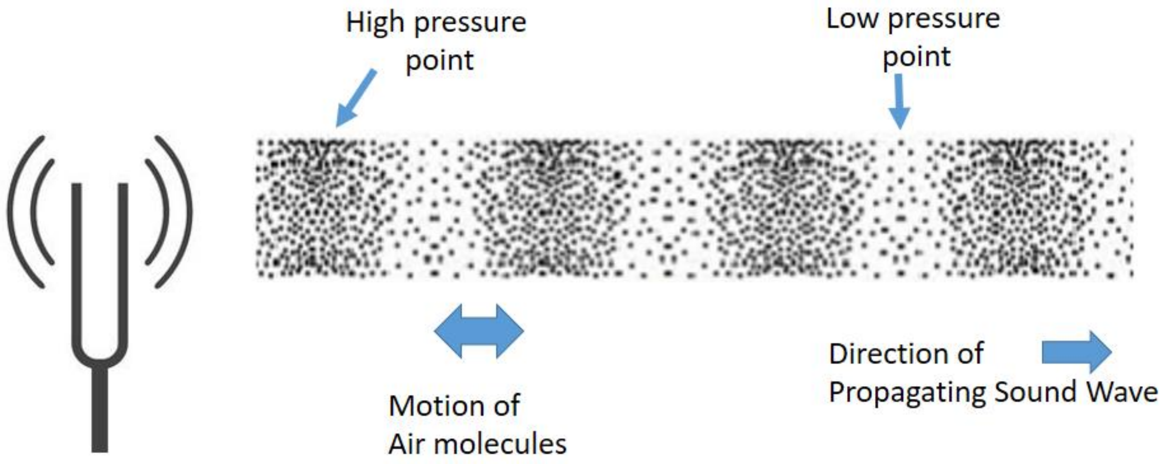
Similar “people waves” are sometimes produced at sports stadium to celebrate the victory of a team. These waves involve tens of thousands of people and are a spectacle to see.

See for example this “stadium fan wave” generated in the state of Michigan in USA in 1984.

https://www.youtube.com/watch?v=79soqk-Oxts

A sound wave is similar to the waves we have seen in the above two examples. The only thing is it is not easy to see a sound wave propagating through air, although there are some sophisticated ways of doing it.

We have seen earlier that, when you blow into an air column, the air inside the air column goes though cyclical compression and decompression at a given frequency. The illustration below shows how such compression and decompression propagates like a wave through the column, just like the water wave above.



On the left you see a vibrating tuning fork. When the right arm of the tuning fork swings to the right, it compresses the air nearby creating a local high pressure point. After a little while, that compressed air volume tries to decompress itself with the air rushing out. This creates a compressed section of air adjacent to the previous section. Where there was a compression before now becomes decompressed. Thus a wave of compression and decompression propagates outwards from the source of the sound.

7.1. Doppler Effect

Have you ever observed a train rushing past you at a high speed with its horn blaring at full volume? It is an exhilarating experience. You can feel all the massive power of a heavy train moving at a breakneck speed. In addition to this feeling of power, if you pay attention to the horn of the train as it speeds past, you will notice something interesting. As the train approaches, you will notice that the horn is quite shrill, and the moment the engine passes you, you will notice that the shrillness of the horn drops suddenly to a lower level.

You can observe the above effect in the following video that shows an Amtrak train (USA).

https://www.youtube.com/watch?v=rPMILdunSCw

Austrian physicist Christian Doppler first studied the reason behind this phenomenon and published his findings in 1842.

Shrillness of sound is related to its pitch or frequency. So far from our discussion of sound, we were under the impression that frequency is an intrinsic property of a sound source. Then how can frequency depend on the motion of the sound source?

It is straightforward to explain why this happens. First of all, let us note that in the first part of the experiment, when the sound is shrill, both the train and the sound are coming towards you. In the second part of the experiment, the train is moving away from you, while the sound from the train is now traveling backwards to reach you. This important difference is crucial in explaining the difference in sound frequency.

When the sound source emits sound, the sound travels towards you – at the speed of sound, of course – as a series of compression and decompression waves. The train itself is initially moving towards you at whatever speed it is moving at (say 100 kmph). Alternatively, you can also imagine yourself moving towards a 'stationary' train at 100 kmph. Both situations are equivalent since the relative velocity is the same. Let us stick to the second situation, since it will make it easy to present our arguments.

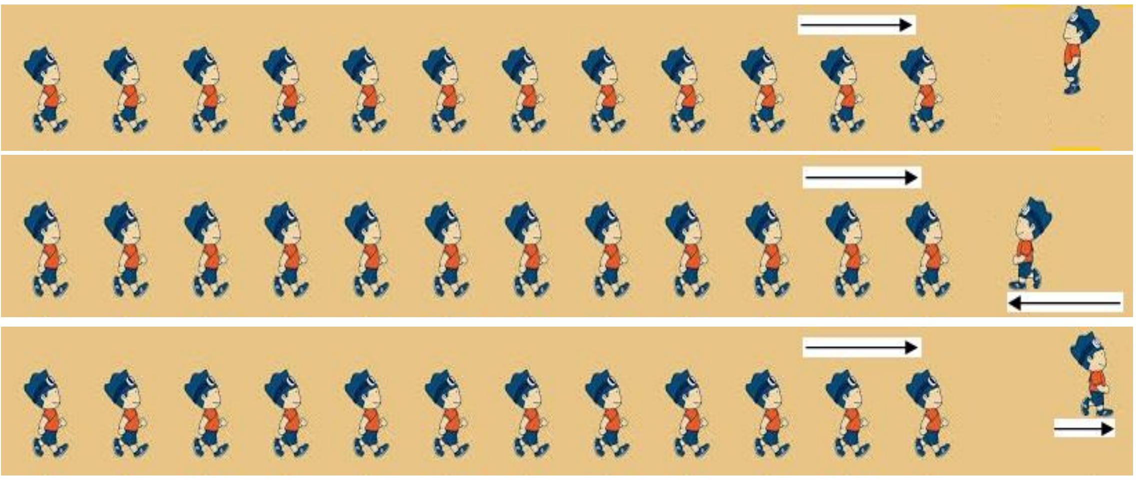
Now let us replace the above situation with a simple analogy. Replace the compression waves of sound with a row of people moving towards you in three situations. In Situation #1, you are stationary while the row of people are moving towards you. In Situation #2, you are moving towards the row of people facing them. In Situation #3, you are moving in the same direction as the row of people.

Since each “person” in the “row of people” represents one compression wave, note that the number of people passing you in one second, represents the frequency of the sound.

In situation #1, when you are standing still, the number of “people passing you” will correspond to the natural frequency of the sound source.

In situation #2, when you are moving towards the row of people, more people will be passing you per second since you are moving in the opposite direction and the velocities add up. This corresponds to an increase in frequency or pitch.

In situation #3, fewer people will be passing you per second since you are moving in the same direction and the velocities partly cancel out each other. This corresponds to a decrease in frequency or pitch.



Doppler studied the above phenomenon and came up with a formula to calculate the frequency of sound that is heard by the observer. In this formula *c* is the speed of sound in air, v_s is the speed of the source (in this case, the train), f_0 is the original frequency of the horn, f is the frequency that is heard by the observer.

When the source is moving towards the observer, a minus sign is used in the denominator as shown below. Therefore, the sound frequency heard by the observer, before the train passed him is,

$$f_{before} = \left(\frac{c}{c - v_s} \right) f_o$$

When the source is moving away the observer, a plus sign is used in the denominator as shown below. Therefore, the sound frequency heard by the observer, after the train passed him is,

$$f_{after} = \left(\frac{c}{c + v_s} \right) f_0$$

Since the denominator is greater in case of “after” than in case of “before”, f_{after} is smaller than f_{before}. Therefore, the pitch of the sound is smaller after the train had passed the observer, than before.

Doppler’s original intention was not to study changes in the pitch of train horns. He wanted to understand changes in the colour of the light emitted by distant stars in the universe. Colour for light is what pitch is for sound: colour depends on frequency of light whereas pitch depends on frequency of sound. We know that visible light consists of 7 colours from violet, indigo, blue, green, yellow, orange and red (VIBGYOR). Among these colours violet has the highest frequency while red has the lowest frequency. Just like in case of the horn of a moving train, when a star is moving towards you the frequency (colour) of the light emitted by the star shifts towards higher frequencies or towards violet. When a star is moving away or receding from you the frequency (colour) of the light emitted by the star shifts towards lower frequencies or towards red. It turns out that, due to expansion of the universe, most starts are moving away from us. Therefore, starlight that we see is slightly redder than what it actually is.

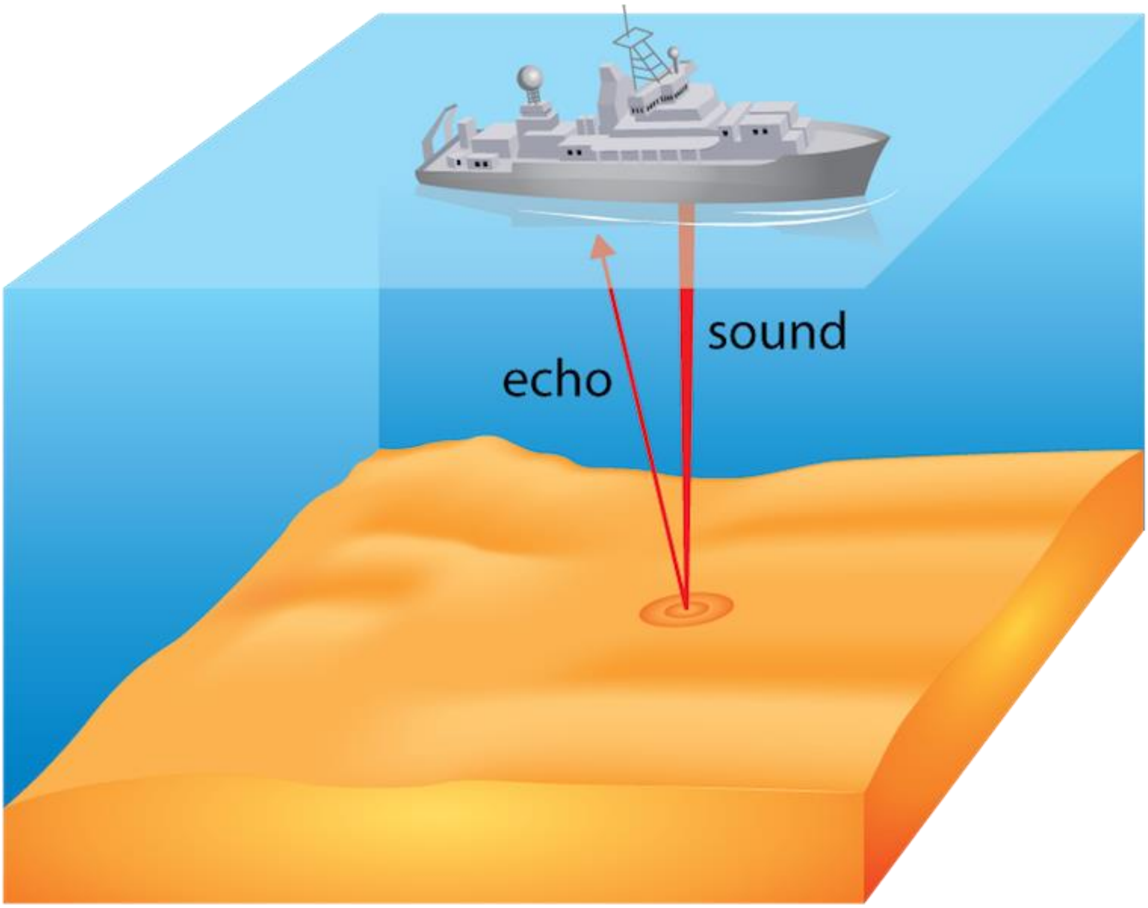
8. Using sounds in the Real World:

8.1 Sonar:

The sonar is used by ships and submarines to estimate distances of targets underwater. The basic principle of sonar is very simple. A sonar device can both emit and detect sounds. These sounds are brief sounds known as “pings.” The sound emitted by a sonar falls on a target and returns to the sonar device after some time as an echo. The device estimates the time taken (2T seconds) for the sound to come back. Half of that duration (T seconds) gives the time taken for the sound to travel from the sonar to the target. Since we know the speed of sound in water (S = 1500 meters/second), the distance of the target is given by the formula:

Distance = S X T

Using a sonar it is possible to map the ocean floor, that is to find out the depth of the ocean at various points. As ship passes over a stretch of the ocean floor it keeps “pinging” the ocean floor, thereby estimating the depth at each point using the above formula.



Mapping the ocean floor using a sonar

Echolocation in bats

8.2 Inaudible sounds – the Ultrasound:

There are sounds that fall outside the range of audible sounds. For example, there is the ultrasound with frequencies higher (“ultra”) than the audible range. Ultrasound frequencies are in the range of 1,000,000 to 5,000,000 Hz, more compactly expressed as 1 to 5 mega hertz or MHz (Mega = 1,000,000).

Ultrasound has immense medical applications. Just as a sonar can be used to map the ocean floor or to detect objects underwater, an ultrasound probe can be used to understand the arrangement of organs in the body. Ultrasound signals propagate through the body and get reflected off the surface of organs. From the time it takes the reflected signal to come back to the probe, the ultrasound device can calculate the distance of the surface of the organ from the probe.

This ultrasound image shows the presence of a fetus inside a mother’s womb

8.3. Supersonic flight:

Flying at speeds greater that the speed of sound is known as supersonic flight. Sound travels at about 1,236 kmph at sea level. Large commercial aircrafts today travel at about 900 kmph, which is about 3/4th of the speed of sound. Some military planes however travel faster than sound.

For a long time people thought it is not possible to travel faster than sound, a myth that was first shattered in October 1947. Earlier attempts at approaching the speed of sound ended in a disaster. As the aircraft approached the speed of sound it shook violently as if it was up against an invisible wall. Just a year before, when British pilot Geoffrey de Havilland tried to fly his airplane close to the speed of sound, the aircraft shook violently and broke apart. The incident made scientists believe that it is not possible to fly at faster-than-sound speeds.

But in mid October 1947, a young American pilot named Chuck Yeager attempted what his predecessors failed to achieve. He wanted to fly at supersonic speeds a special plane called X-1 developed by Bell Aircraft. This aircraft was designed for high speeds and was described as a “bullet with wings.” As he increased the speed of the aircraft, first it shook violently. But as the speed climbed, the shaking stopped. Then he noticed that the needle on the speed gauge went off the scale. The aircraft broke the sound barrier! Just at that time those who were observing the plane from the ground heard a loud boom as if a bomb had exploded. This boom that is produced when the aircraft exceeds the speed of sound is called a ‘sonic boom.’

A remarkable passenger aircraft called Concorde was in use for a long time connecting North America and Europe. Traveling at nearly twice the speed of sound, it would cover the distance between New York and London in 3.5 hours. But after a disastrous crash in the year 2000, passenger numbers dropped. Therefore, the aircraft was put out of service from 2003.

Why is a sonic boom produced?

It turns out that not just in case of aircrafts, but when any object moves in the air at speeds greater than sound, it produces a sonic boom. A curious domestic example of sonic boom production is a whipcrack. When you flick a whip in the air, even though the tip of the whip does not touch any solid object, the whip produces a loud "cracking" sound called the whipcrack. This happens because, when the flicking movement is performed by an expert, the tip of the whip exceeds the speed of sound.

How do we know?

Engineers have measured the motion of the tip of the whip using high speed camera and found just at the point when the tip crosses the speed of sound – or breaks the sound barrier – a loud sound is produced. See this video to see how such an experiment is performed:

https://www.youtube.com/watch?v=cVpr9ufcMOI

Concorde passenger aircraft capable of supersonic flight