NOISE CONTROL IN MECHANICAL SYSTEMS

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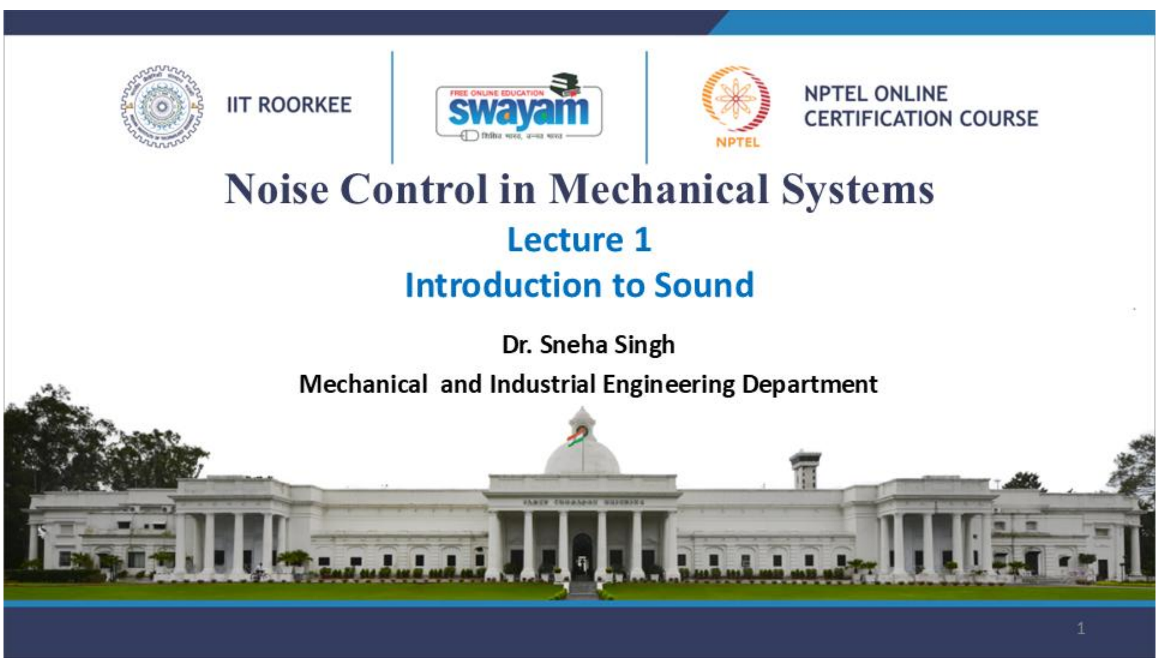
IIT Roorkee

Week:1

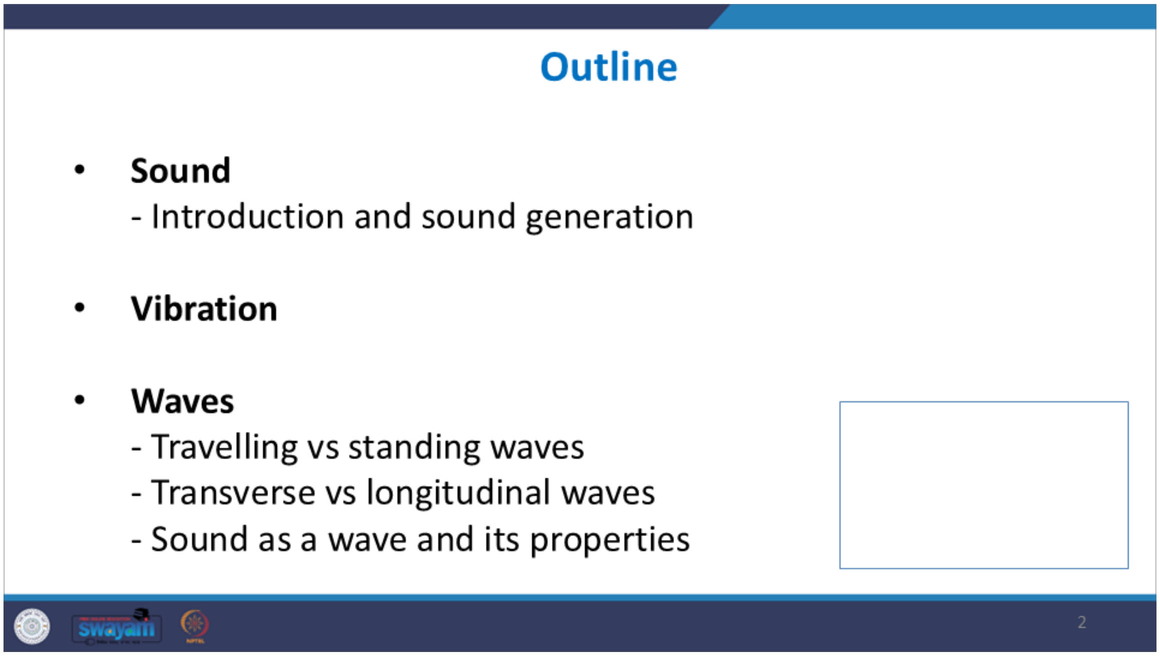
Lecture:1

Lecture 01: Introduction to Sound

So hello, welcome to the very first lecture in the lecture series on noise control in mechanical systems. And this is the lecture one, which is introduction to sound. I am Professor Sneha Singh from the Department of Mechanical and Industrial Engineering at IIT Roorkee.



So, the outline for this introduction is that we'll first introduce to you the phenomenon of sound not just in the layman language but as well in terms of the physical phenomena.



Then we will go ahead and distinguish it from the phenomenon known as vibration and then sound is essentially represented in the form of a wave. So, we will discuss sound as a wave and we will discuss about the various types of wave and the properties of sound as a wave.

So, let us begin this lecture. So what is sound? Now, sound is something which all of us are familiar with in our everyday life.

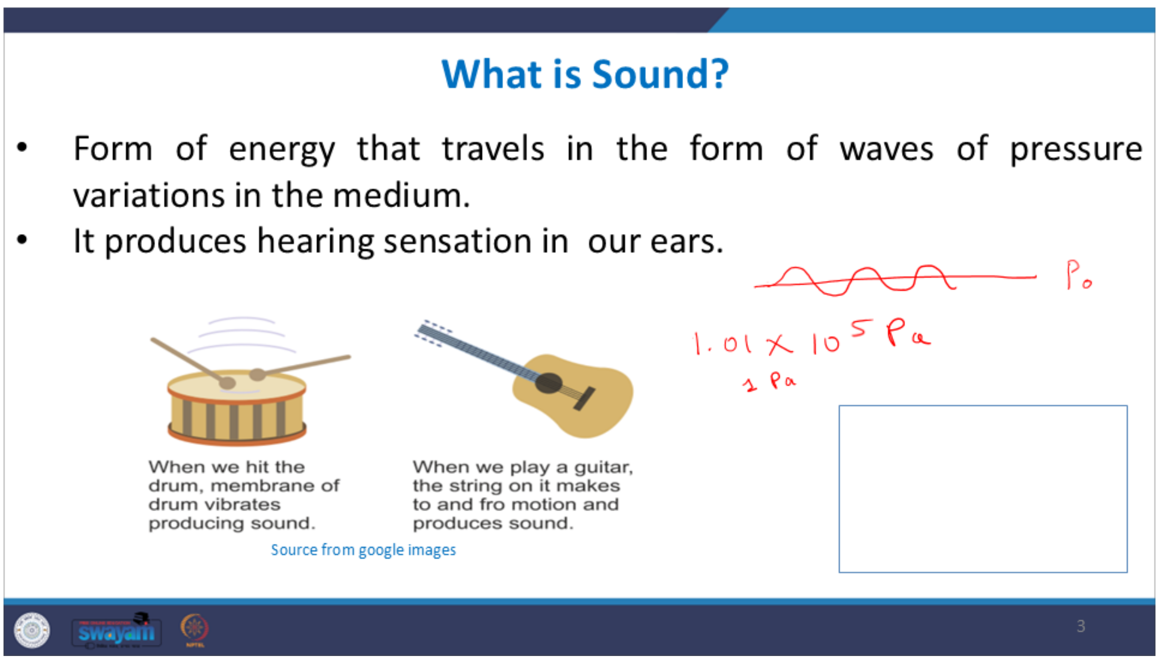
We Right now, whatever I'm speaking, you are hearing this in the form of sound. So what is it? In the layman language, you can say that sound is a sensation that we perceive in our human ear and we receive the information through that. And it is what? It's a form of energy that travels in the form of waves of pressure variations in the medium.

So, what do I mean by this? So, let us imagine I am standing here and we have this atmosphere or the air as a medium. Now, this air has got its own equilibrium atmospheric pressure. Now, due to some reason let us say some phenomenon created some sort of variation in the air pressure. So, let us say I had this as the ambient pressure P0.

And due to some reason, there was fluctuations. So, slight increase in the ambient pressure, then slight decrease, increase, decrease and so on. And that small fluctuation in the pressure. Now, I am talking about very small fluctuation. So, let us say we have our atmospheric pressure that is

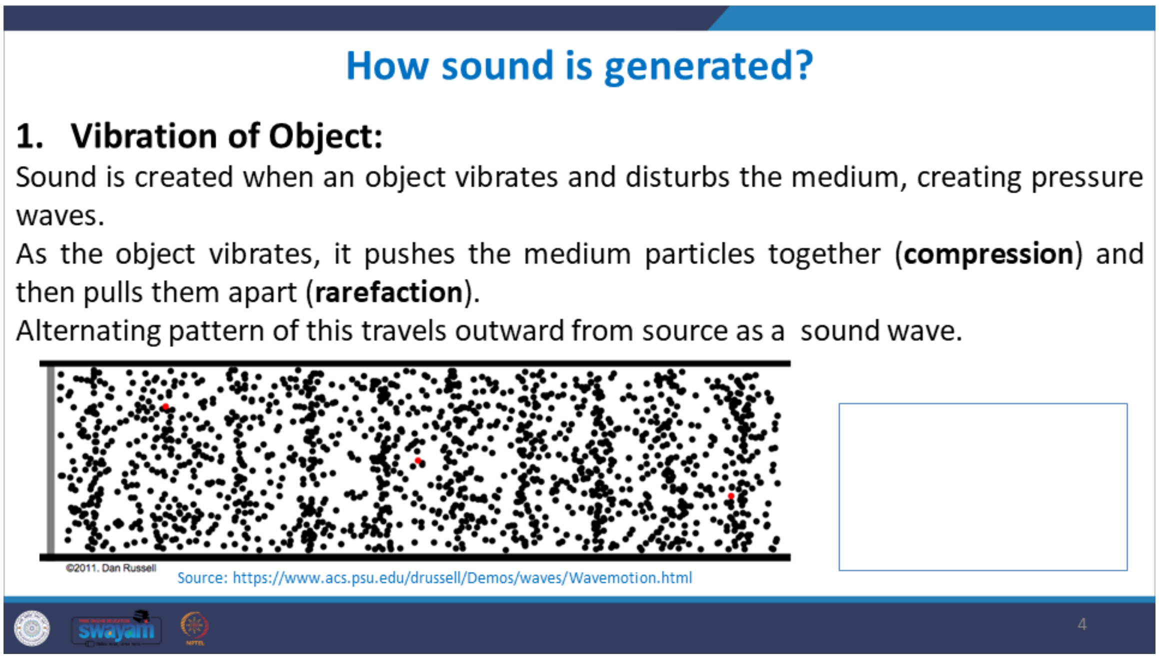
an order of magnitude of 10 to the power 5 pascals. And let us say a very minute pressure fluctuation has been superimposed into it. So, just it is 1 pascal fluctuation up and down which we are not going to feel anyway because it is very small in magnitude compared to the actual pressure. But this very small fluctuation itself is perceivable by the human ear as a very loud sound of 94 decibels, a very loud sound indeed.

So even minute variations in the atmospheric pressure they travel through the air and then they are collected by our ear drum in the ear which vibrates and creates a sensation that our brain then receives as the sound.



So let's see how sound is generated. They are basically Various mechanisms that are available but given the level of this course will study about three main types of generation mechanism for sound. The first one and the most common one is the vibration from an object.

Suppose for example I am standing here and I start to sort of vibrate this table or anything for that matter continuously over time is going to create some kind of sound. So, any object that is vibrating it is going to push the air particles back and forth and some kind of pressure variations will be introduced. So, I have in the very first lecture slide told you that sound is basically a sinusoidal it is a pressure variation. And you can vary the pressure of the atmosphere using vibration of an object. When the object is vibrating, it is pushing the air particles and as the air particles are being pushed together and pulled away, their relative pressure for that time is coming up or down and a pressure variation has been created. you can see it over here with this schematic so here we have this as the vibrating surface this

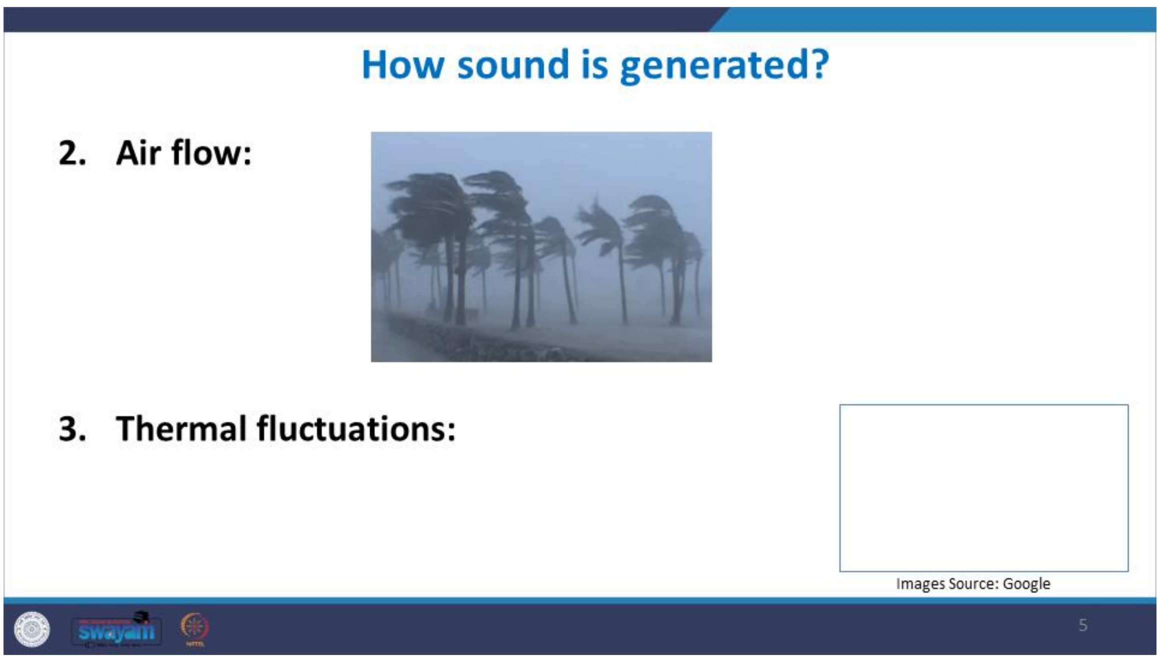


gray thing here which is a piston and this piston is inside a pipe and as it is moving back and forth the particles of the air or the medium they are coming together and the moment they come together they increase the pressure slightly. The moment they go away again, they decrease the pressure. And this particular disturbance of fluctuation in the moment instantaneous pressure is carrying forward as the sound wave.

Similarly, we can also create the sound using air flow. I will give you an example of a very stormy weather. Let's say we are somewhere we have a house located in the middle of nowhere. Almost there is From till far away there are no reflecting objects or structures nearby and we have a very stormy night and the air is blowing away.

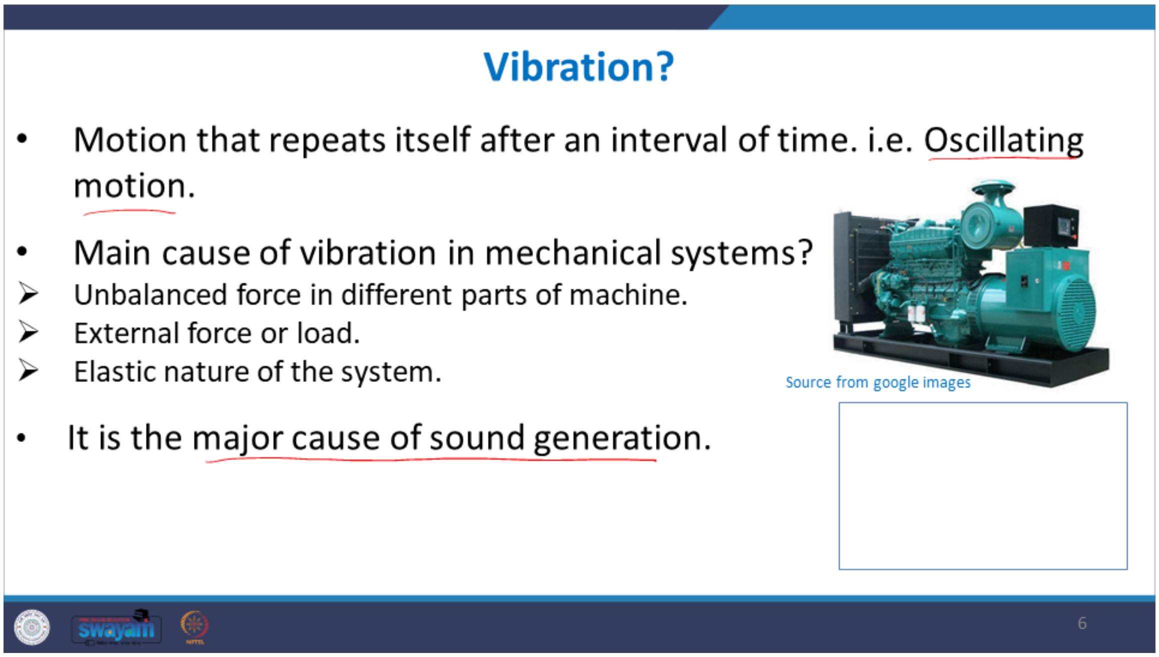
You can hear literally hear the sound of the blowing air and it is not because of the vibration it is creating in the structure it is the air flow itself that is creating the sound. So, if suppose we have a very turbulent air flow then that turbulent air flow can have some harmonic components inside it, it can fluctuate the momentary pressure of the atmosphere and it can create sound waves. In the same way what could be the other way of having this pressure variation? We know that if we heat a particular gas any gas or air then when we heat it the Particles, they move away, the air expands and the pressure goes down a bit.

When we cool it, the particles compress or come together and the pressure increases. So, suppose we had certain mechanism by which we could alternately increase and decrease the pressure at a very high rate, then we can create a pressure fluctuation that can be perceived as sound.



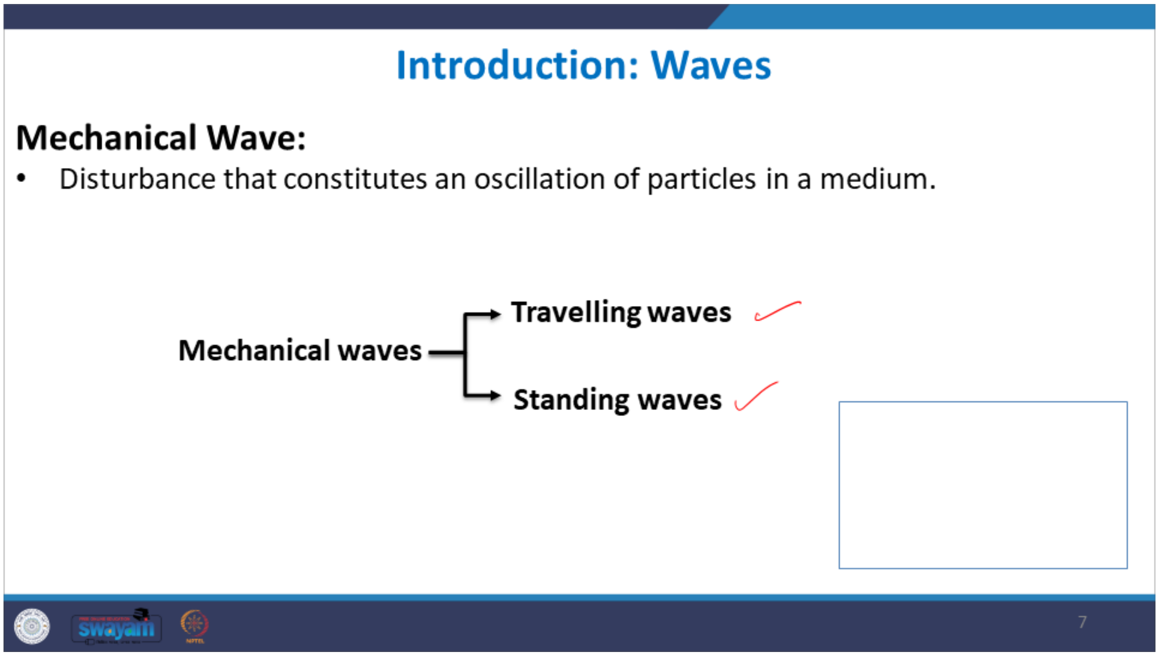
So, let us talk about vibration. Just one slide I will devote to that. So, vibration is the most common phenomenon or the most major cause of sound generation and because our lecture is on noise control in mechanical system.

So, anything we discuss we are going to put it in the context of a machinery or a mechanical system. So, what is vibration? It is a motion of an object or a surface that repeats after an interval of time or you can rather say it is a oscillating motion. okay it's a major cause of vibration and in most of the mechanical systems it happens due to some unbalanced forces in different parts of the machinery due to some external loading or due to the elastic nature of the very system itself because of its elasticity even if there is any unbalanced force component or even if there is small displacement of any part of the machinery from its equilibrium position it will try to regain its original position that can set that particular component into a vibratory motion.



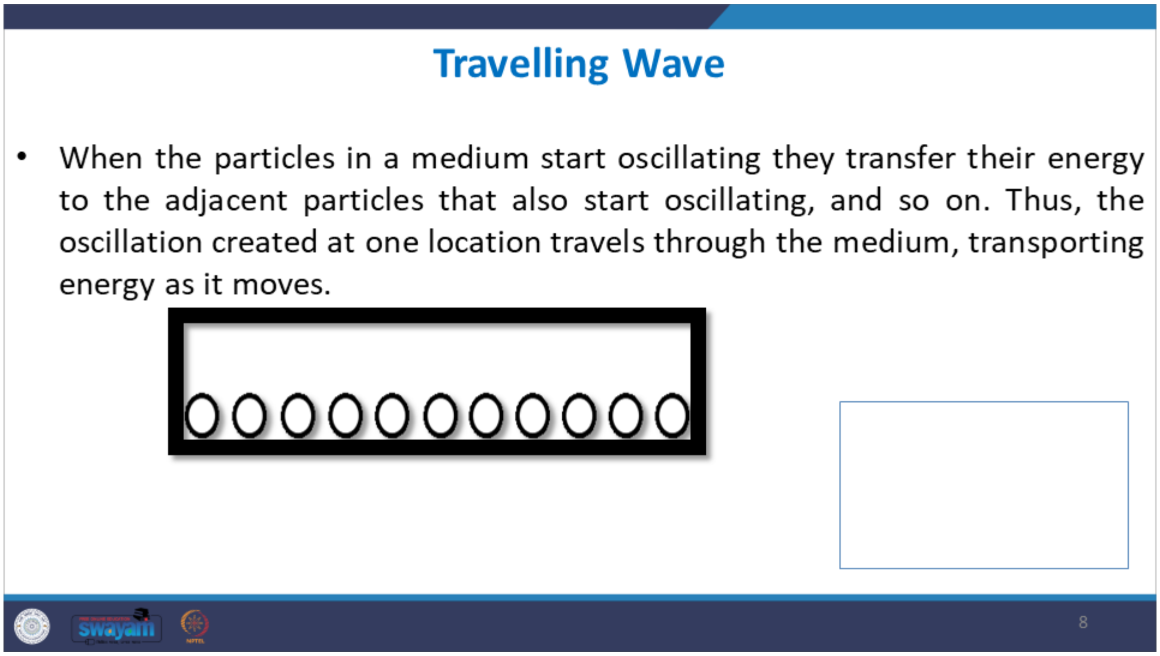
Okay, now sound as I said to you is a pressure fluctuation and I would like to refer back to this slide here where you can see the increase and the decrease in the pressure that is being carried forward in time. So, a very good way to do all the mathematical representations of sound and solve various problems related to sound waves and noise control is to represent this particular phenomenon in the form of a wave. So sound essentially becomes a wave. It's a disturbance in the pressure that is being carried forward. So we'll give you a brief context of the waves itself.

So, mechanical wave is what? It is a disturbance that constitutes oscillation of the particles in a medium. It can be travelling or standing.



Travelling wave is when a particle in the mediums they are oscillating and they are not just oscillating the particles in one layer they are oscillating and while oscillating they are hitting the other layer particle and they are transferring their energy to the next layer of particles. And then the next layer of particles they are oscillating and then they are also transferring their energy to the further next layer of particle and so on.

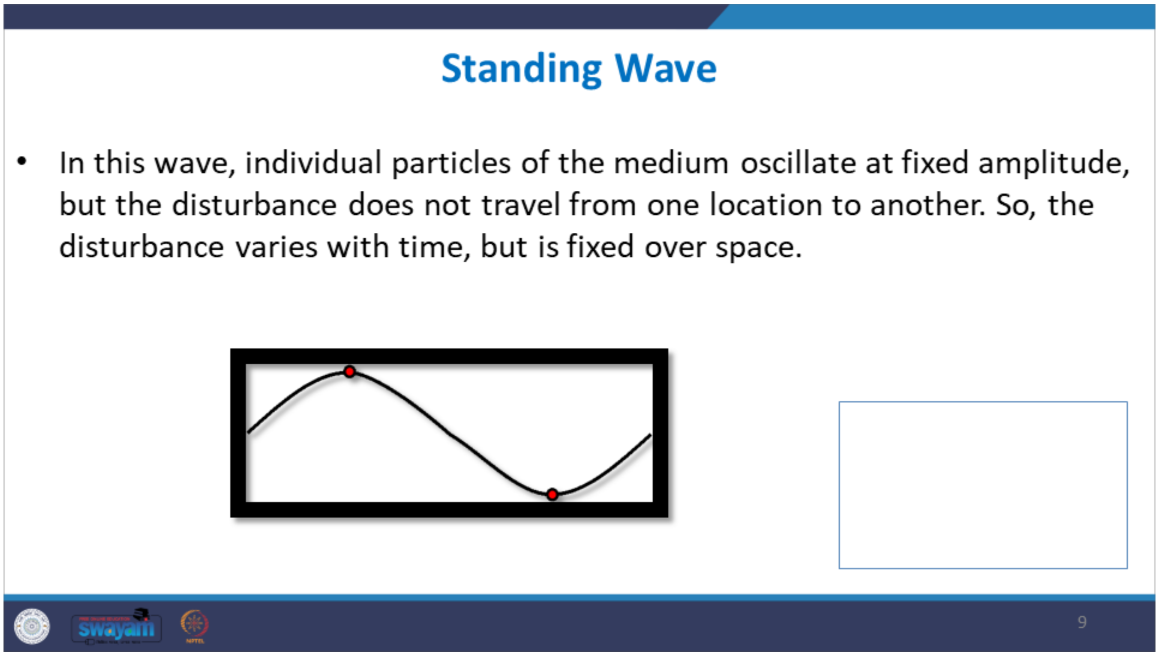
The particles they oscillate and also transfer their energy in progression towards the next and the next layer of particles and the overall disturbance carries forward in space. So when the disturbance is going from one location to another location in the space, it becomes a traveling wave. It's carrying the energy forward.



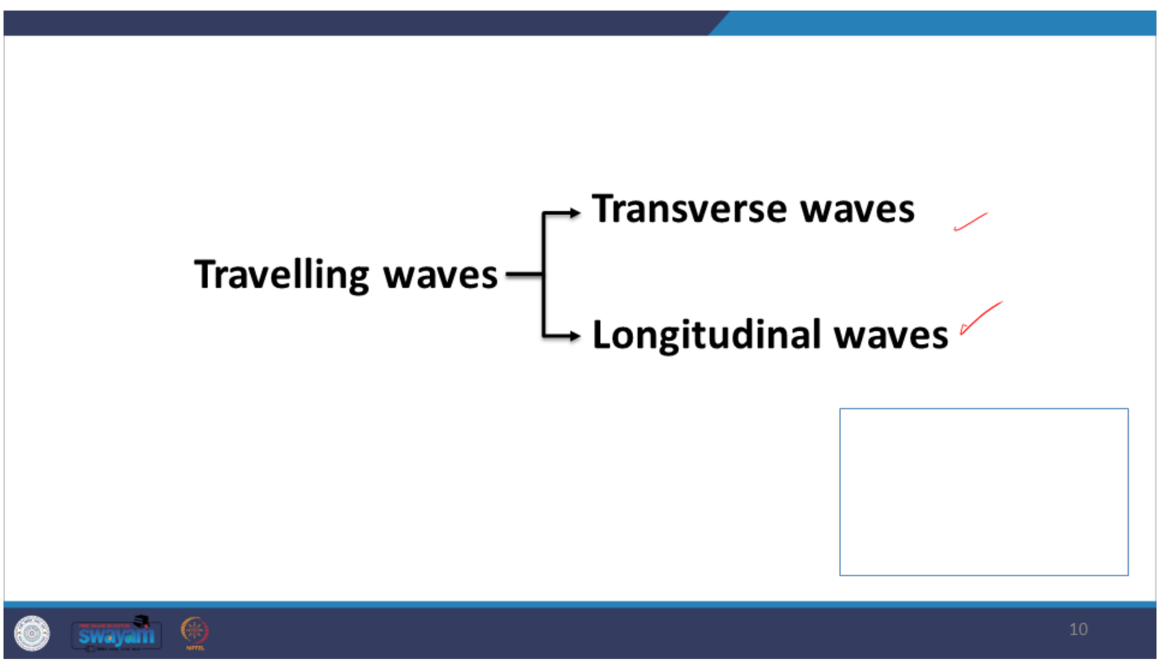
Whereas, we can also have a wave where the particles are oscillating, there is a disturbance, but it is being confined to a closed space.

Usually, in closed cavities, closed rooms, we can experience standing waves and modes.

So, the particles oscillate, but the wave propagation has been cut off because of some confinement in the space itself that becomes a standing wave.

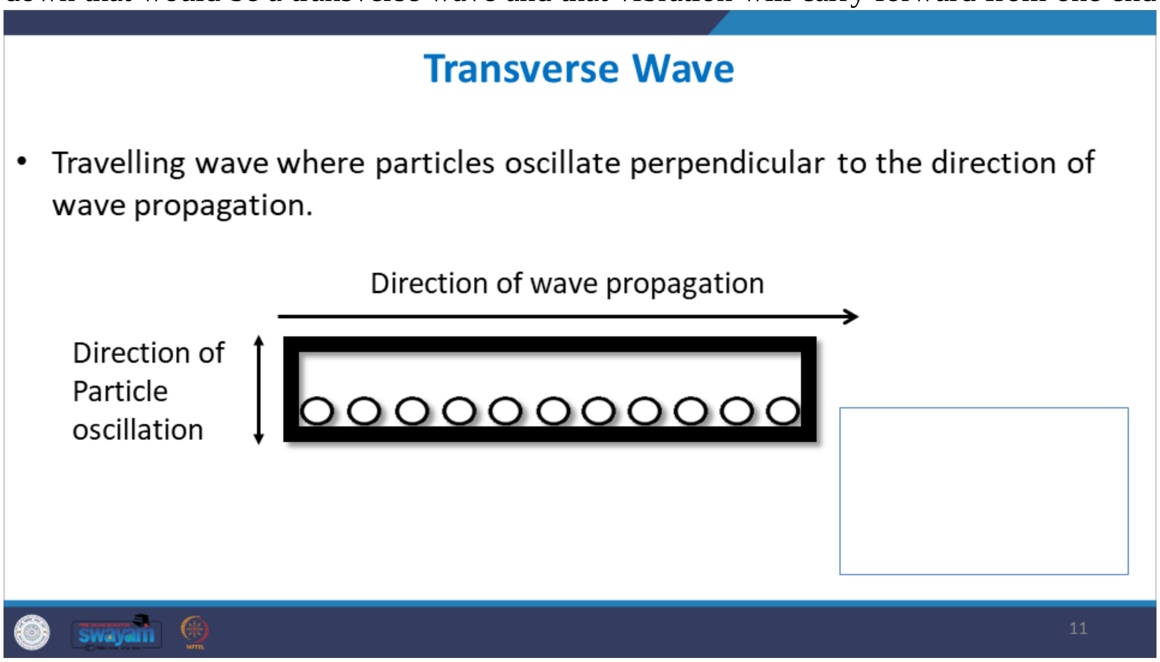


And in the travelling waves, which are the most common waves, which we will be referring to in this particular lecture series, we have the transverse wave and the longitudinal wave.



The transverse wave is when the medium particles, they are oscillating in the direction that is perpendicular to the direction of wave propagation. So, if you look at this schematic here, here the particles are oscillating up and down and the disturbance, which is represented by these red balls here, which are, towards the peak of the wave that is going forward in the let us say positive x direction or the horizontal direction whereas the particles they are oscillating in the vertical direction.

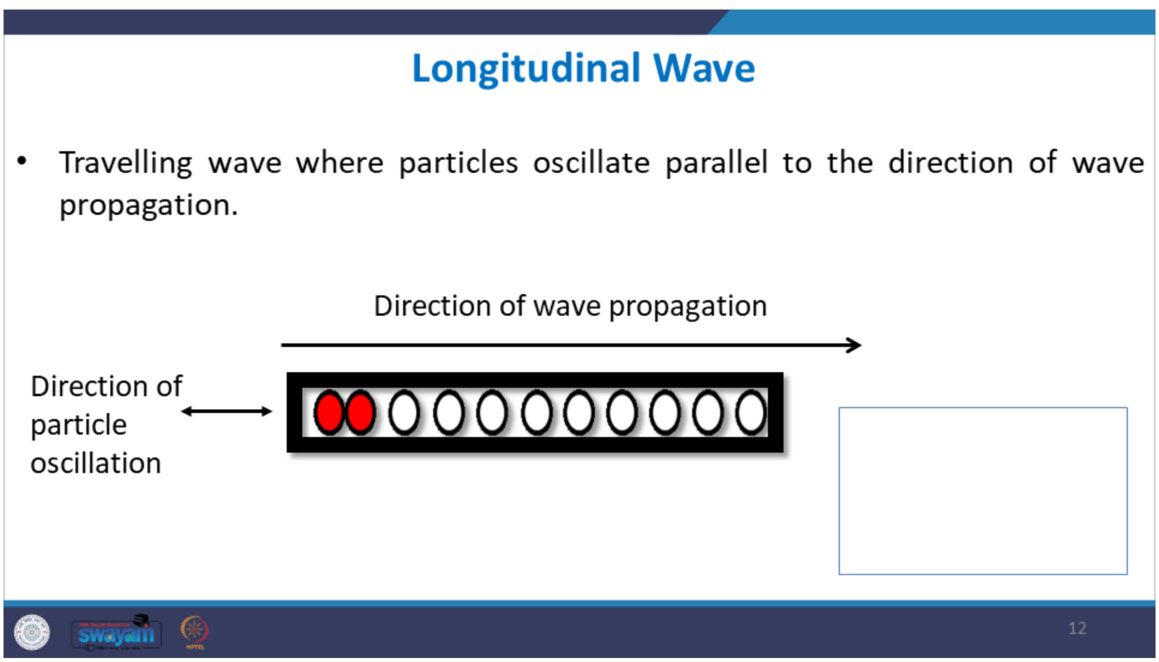
One example you can think of is that suppose you had a string let us stretch the string and then just pluck it for example the string of a guitar if you pluck it it will vibrate up and down that would be a transverse wave and that vibration will carry forward from one end



to the other end of the string.

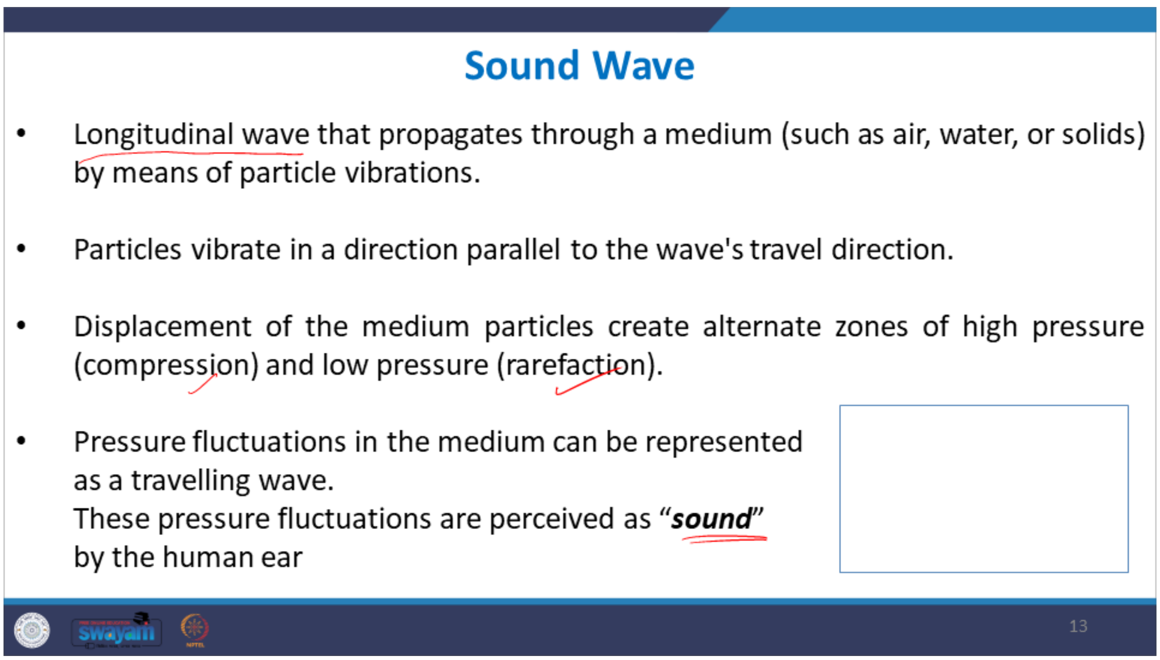
Then what is a longitudinal wave? The same way what we can have is that the particles they are moving back and forth in the same direction as the direction of the wave propagation as seen in the schematic here and while travelling in that same direction what they are doing is they are transferring the energy. So, here once the particle is oscillating it is coming together moving apart coming together moving apart and in that process it is transferring its energy to the successive layers of particle and the overall disturbance is propagating forward.

Now, if you recall the schematic I had for the sound wave in the very first few slides you could see that the particles they were oscillating in the same direction as the direction of the wave propagation. So yes, sound actually is a longitudinal wave.



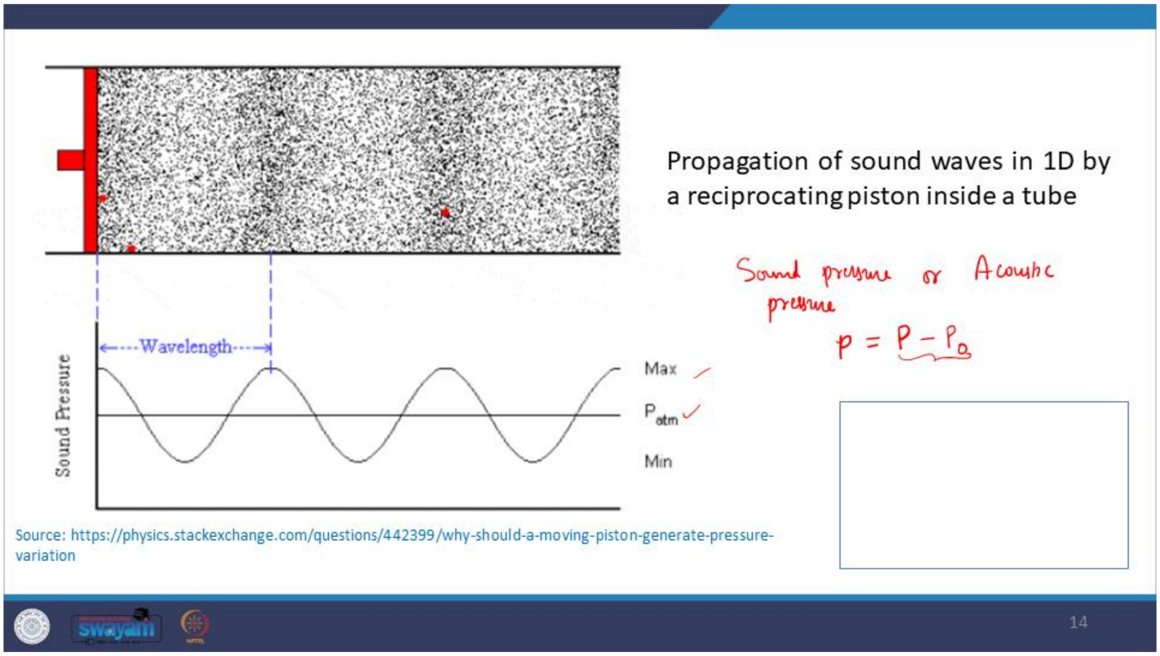
Ok. So this is a longitudinal wave. It is propagating through a medium such as air, water or solids by the means of particle vibrations.

Suppose we had vacuum here and I started talking, you would not be able to hear my sound. Because sound is a mechanical wave or an elastic wave, it always needs a medium particle to transfer its energy in contrast to electromagnetic wave. Here the particles because sound is a longitudinal wave, they are travelling. They are vibrating in the same direction as the direction of travel of the sound wave propagation. And when the particles they are traveling they are momentarily increasing or decreasing the pressure that is they are creating the zones of compression and rarefaction. ok. And this pressure fluctuation is what we represent in the form of wave and we perceive a sound by the human ear.



So let's see here how to represent it in the form of a wave. So again the same piston trying to move the air particles back and forth and in the process it's creating this wave. Now, suppose we can represent the pressure, the overall pressure in and see its variation over time or space.

So, let us see here we are plotting the pressure of the medium. So, for some moments it is increasing in these zones where the particles are pressed together. You have a slightly higher pressure than the actual atmospheric pressure. And then in the zones where they are



furthest apart, you are having the pressure that is lowest. So, we are representing this pressure.

And from now on, whenever we refer to sound pressure, which we also call as acoustic pressure. So, whenever we have the sound pressure or the acoustic pressure, what happens is that it is actually this minute variation in the atmospheric pressure. So, let us say P is the total instantaneous pressure and P0 is the mean atmospheric pressure. Then at any time instance this small P can either be 0 which is over here when the wave is cutting this horizontal line.

Then in some moments the P could be positive In some moments the P could be negative because the pressure is fluctuating about the mean position which is P0. And this fluctuation or small p or the difference becomes your sound pressure.

So let us represent this. The sound pressure if you think would be a function of what?

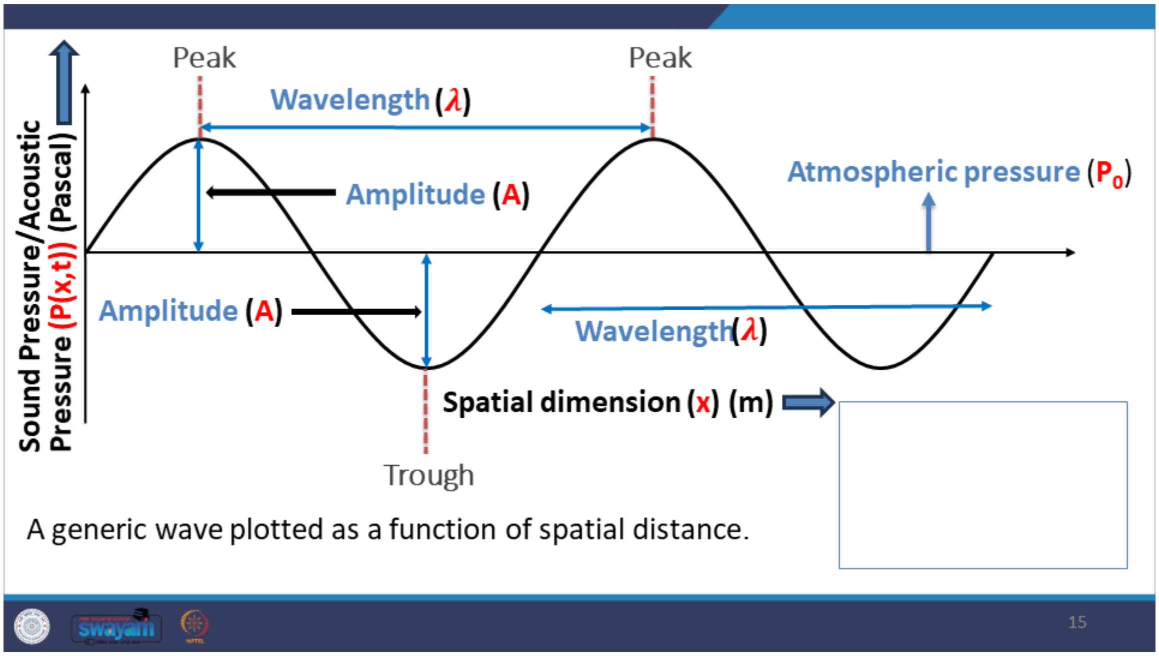
It would be a function of both time and space. Let us say for example I am delivering this lecture to you and I am speaking something. So I am standing here and my sound wave is flowing away from one location to the location of the listener. Let us say I am standing in a class, delivering a lecture. The students are sitting there.

My sound wave travels from the first bench to the second bench and to the third bench. But because the speed of the sound is so high, it seems to happen altogether. But there are fractions and fractions of seconds of difference in my sound reaching to the various speakers at the various distances. So, my sound wave is traveling over space, but at the same time there is also a variation with respect to time. Now, at one time instance I might be saying the letter a and then b and c and so on.

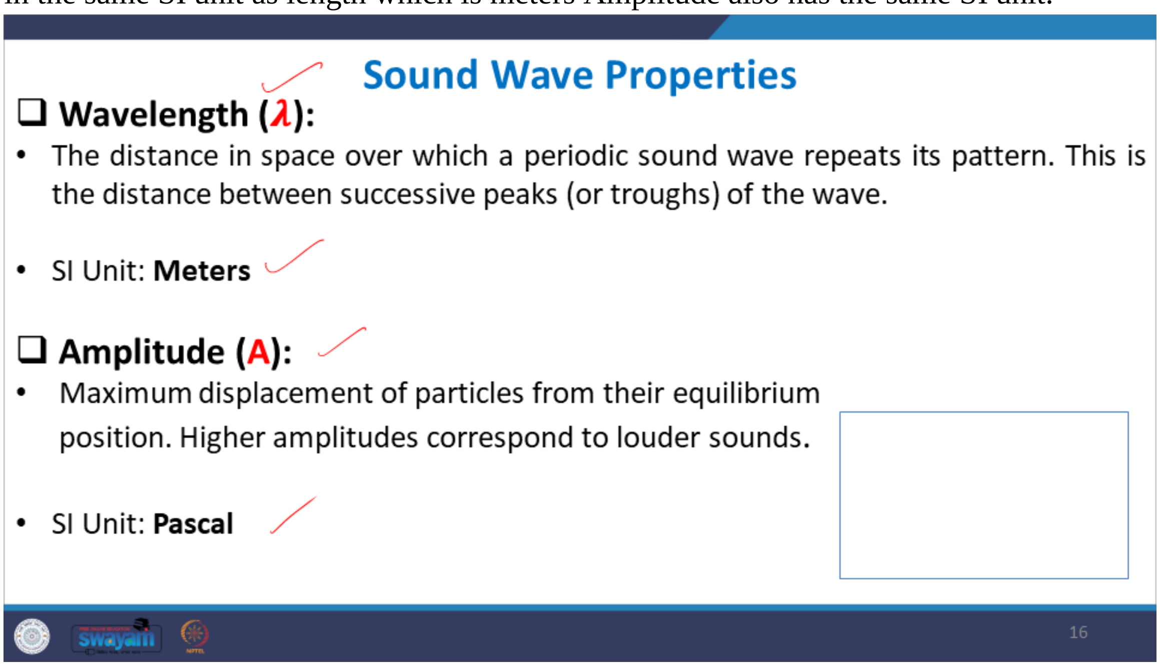
So, whatever I am saying it is also varying with time. So, that is why this p becomes a function of both the space and the time and for simplicity rather than having the p as a function of x, y, z and t. Just for simplicity, we begin with 1D. Okay, so let us do the 1D wave and then we will extrapolate it to three dimensions. So, this is a 1D wave, space and time variation.

So, let us consider one spatial dimension x and what you see is that this wave is travelling from one location to another and we have plotted the sound pressure which is the difference between the total pressure and the mean atmospheric pressure. So here you can see some positions where we are having a peak in the wave and the some positions where we are having the trough. So the difference between the mean pressure and this peak becomes the amplitude. So this is the maximum variation we are able to achieve when a sound wave is propagating and then we are having the wavelength which is the distance between any two successive peaks or any two successive trough.

So, basically it is that spatial distance over which we can make one full wave cycle.

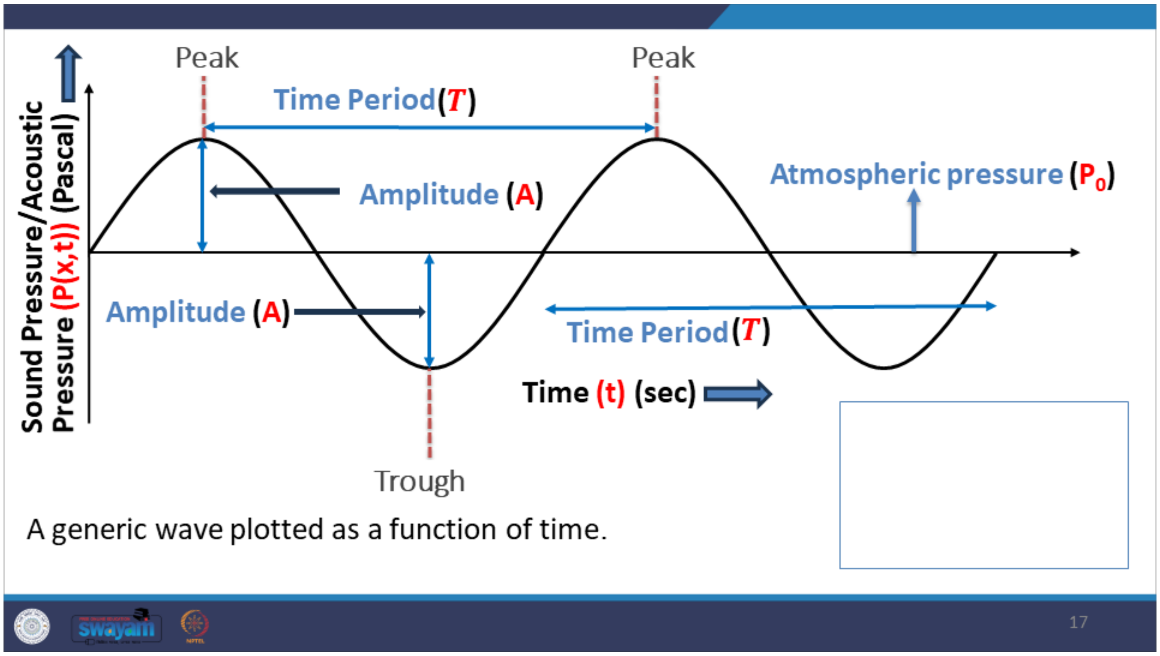


So, that is the wavelength expressed because it is basically a distance. So, it is expressed in the same SI unit as length which is meters Amplitude also has the same SI unit.



Now we can also represent the same wave as a variation over time.

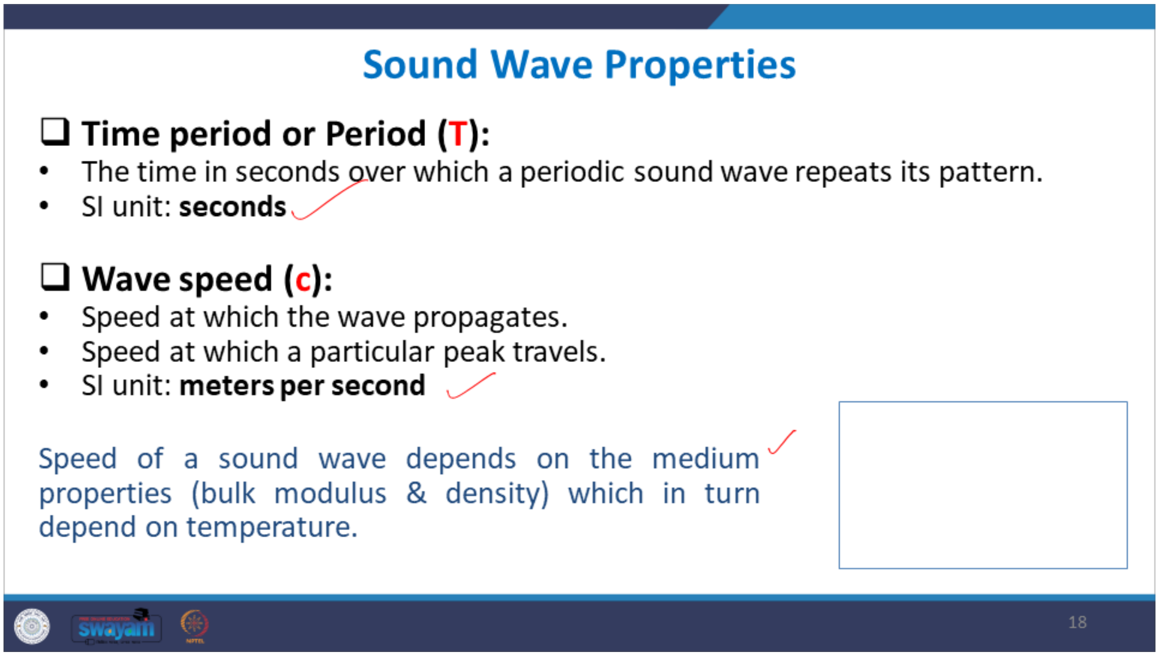
And let us begin with the simplest of the sound wave which is a sinusoidal wave. Suppose you can play certain tones you know like in the various way you have these tones at various hearts. So we are having the simplest of the sound wave and now we are representing its variation over time. So in the same way you have the peak and the trough and the difference is obviously the amplitude which stays the same if you represent it over space or represent it over time. If it is a non-attenuating simplistic sound wave, the amplitude is going to be the same.



And then what is the time period? It is the time over which the wave has repeated its pattern or the time within which we can fit one full wave cycle. So here in this diagram, horizontal axis is the time axis. So it becomes this distance between the two peaks in the time dimension, okay, which is the time period here. It is represented in the SI units of time, seconds.

And another sort of terminology is the wave speed. So I told you that sound is a longitudinal wave and it's a traveling wave. Then it will propagate over space, right? It will go from one point to another. from the time it starts originating and the speed with which it is moving forward in the space becomes its wave speed.

So, the SI unit for which becomes meters per second, you can also say that it is the speed at which a peak of a wave is traveling forward in space. Now, I will just take a little bit of detour here and say that the speed of the sound which will discuss in detail in our third lecture but it is dependent on the medium properties such as the bulk modulus and the density which themselves are dependent on temperature. So, whenever we have any particular medium which is maintained at a constant temperature and has a constant density or bulk modulus throughout then we can very safely say that the speed of the sound remains constant in that medium



okay so some of the terminologies

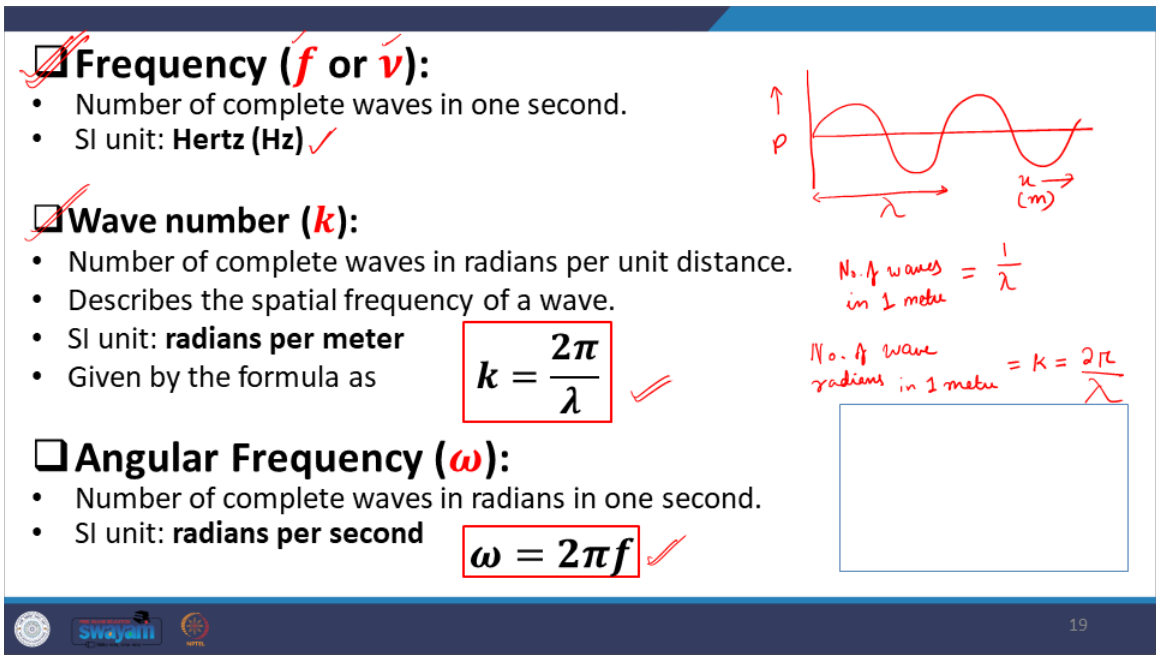
frequency now this is the most important terminology you need to take a note of that because throughout your series on noise control will refer to frequency time and again it's one of the most important properties of a sound wave it's represented by f or this symbol v so what is that it is the number of complete waves that has been created in one second so you already know that it takes a T time the time period or the capital T time to create one wave then what could be the relation between f and capital T it would be f is the inverse of T right. So, the number of waves that are created in one second it is represented in the SI units of hertz or Hz then wave number this is yet another important property. This is the number of complete waves in radians per unit distance. Let us derive a relation.

The relation is already mentioned here, but I will try to derive it here. So, let us say we have a wave here. This is the spatial distance, let us say x or whatever in meters and this is our pressure which I am plotting here and this is some kind of waveform Ok. And this is the distance which is λ which contains a one full wave. Now, we want to say per unit distance how many waves suppose it is each wave is occupying λ meters.

Then how many waves can be there in one meter? It would be $1/(\lambda)$ number of waves in one meter. would be $1/(\lambda)$ because λ is the distance occupied by one wave. So, how many radians? Now, each wave means one 360 degree rotation of the sinusoidal wave corresponding to it.

So, a 2 π radian equivalent to one wave. So, the number of radians of wave will be what? In 1 meter. this by definition is your wave number k this would be 2 π times the number of waves in 1 meter which is $(2\pi)/\lambda$ which is a very important relationship for this particular lecture series then there is another terminology called as the angular frequency which we represent by the term ω this is yet another very important parameter and this is the number of wave radians in 1 second Now, we already know that the number of waves in 1 second is f which is the frequency in hertz.

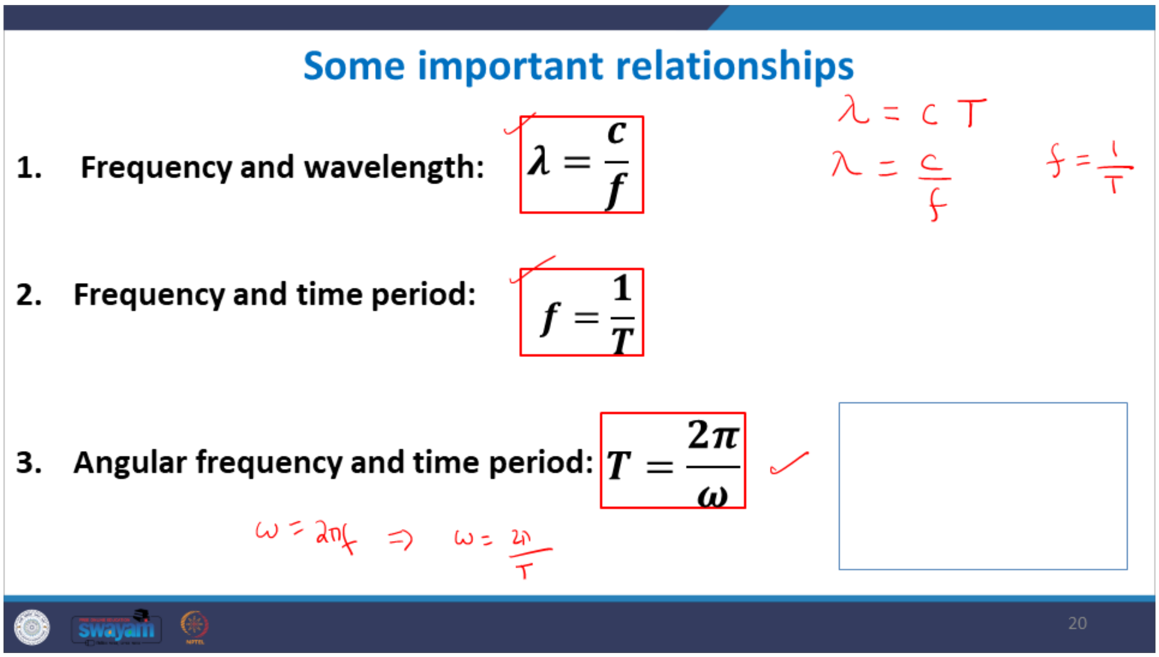
Then the number of radians would be 2 π f because 1 wave is 1 full 2 π revolution of the wave if you represent it as a sinusoidal wave.



Okay, so some very important relationships. between frequency and the wavelength so see the speed of the sound is c so the sound is traveling with some speed c and let us say that it is covering a distance of λ so let us consider a single wave how much time will a single wave need to travel it will need a time of $1/f$ and how much distance will it cover? It will cover a distance of λ.

So, the distance covered by a single wave let us say is λ and this is same as the speed of the sound wave and the time it took to cover that λ and by definition the number the time in which one wave travels is t. This is the time period taken for one full wave. So, λ= cT and f is what is the number of waves in 1 second which becomes $1/T$.

So, λ= c/f ok. So, that becomes your first important relationship and while discussing this we have already derived the second one which is $f = 1/T$. Now the relationship between angular frequency and the time period obviously ω= 2 π f okay and $T = 1/f$. So let's derive the relationship here. ω =(2 π)$/T$ because $f = 1/T$. So, in this way you can derive the relationship between all important parameters



and I think with this note I would like to end the first lecture on our noise control in mechanical systems. So, thank you.