Acoustic Materials and Metamaterials

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Lecture – 01
Introduction

Welcome to the series on Acoustic Materials and Metamaterials. I am Prof. Sneha Singh, I am an Assistant Prof. in the Mechanical and Industrial Engineering Department at IIT Roorkee and I will be conducting this course which is named as Acoustic Materials and Metamaterials. So, this is part of the MOOC and the NPTEL course work and the course structure is as follows.

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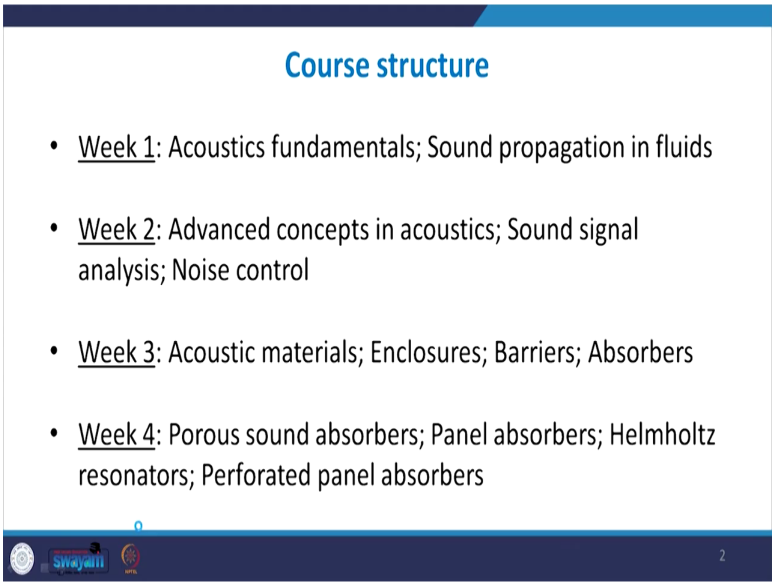

So, this course will be, it is a 20 hours lecture and it will be distributed over 8 weeks. So, in the week 1 we will be studying about some Fundamentals on Acoustics and Sound wave propagation in fluids. So, obviously this fundamental knowledge is necessary to understand what do you mean by acoustic materials and how do they work.

Then in the week 2, we will again concentrate on some of the more Advanced concepts in acoustics and specifically what is Sound signal analysis and what are the Principles for Noise control and then, from week 3 we will start with a discussion on Acoustic materials and then in particular we will study about some Traditional acoustic materials and the Traditional acoustic materials are divided as enclosures, barriers and absorbers.

So, we will study about these three different classes of acoustic materials. Week 4 will be a more detailed discussion on one type of absorber which is the Porous sound absorbers followed by some other sound absorbers such as the Panel absorbers, Helmholtz resonators and Perforated panel absorbers. So, over all week 4 will be dedicated to a detailed discussion on absorbing sound materials.

Finally or in week 5, we will study about another absorber which is called as the Micro perforated panel absorber and when we finish about discussing about this last type of absorber then together we will study about the limitations of the conventional acoustic materials.

So, before that in the previous weeks we will discuss about what are the various Acoustic Materials, their classes, the different types enclosures, barriers and sound absorbers and then what are the general limitations of these materials and based on the limitation we will able we will be able to understand why do we need a new type of material for noise Control, so, what is the need for an acoustic metamaterial.

So, that is what we will be discussed in week 5. Week 6 will be a further discussion on acoustic metamaterials and then a new type of acoustic metamaterial called as the Membrane Type Acoustic Metamaterial will be studied.

In week 7, further discussion on Membrane Type Acoustic Metamaterials specifically on the types of unit cells used, what is the performance, what is the function of response of that unit cell and what is the response function like, what are the applications of this unit cell. So, all these things will be studied in week 7 and then, there will be an introduction to the second type of metamaterial which we will be studying in this course which is the Sonic crystals.

So, Sonic crystals will be introduced in week 7 and the more detailed study of Sonic crystals later many about the type of Sonic crystals used, the type of wave, the type of sound attenuation they do, what are the factors that the sound attenuation depends on and what are the applications of this Sonic crystals.

So, more advanced concept in sonic crystals will be studied in week 8 and then a few guidelines will be given to you on how do you select a material for a specific Noise control application and with that the conclusion will be done. So, after just going through briefly about what is this course about and what are the and how is the course structure distributed, I will now start with the first lecture and the first lecture is a lecture on the fundamentals of acoustics or acoustic fundamentals.

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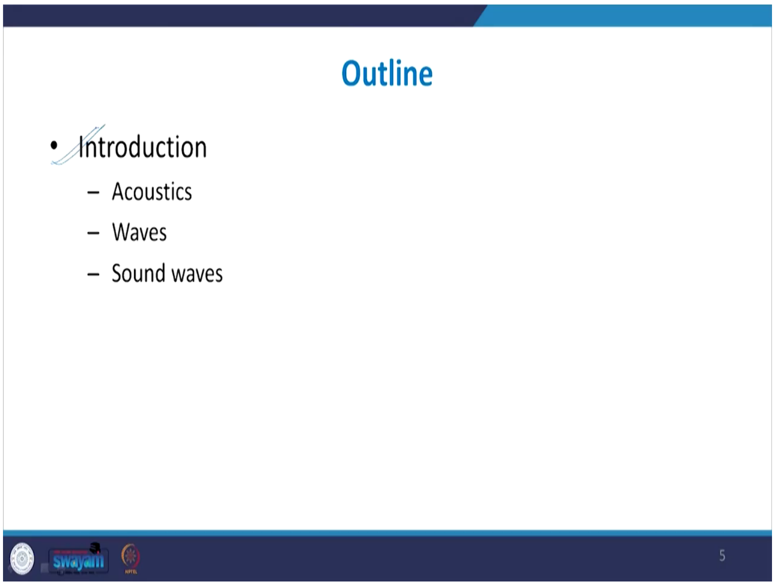

So, in the first lecture what I will be covering is I will introduce to you in general the terminologies like what is acoustics, what is the study of acoustics, what do you mean by waves and then what do you mean by Sound waves. So, this is a very introductory course and very fundamental course towards understanding field of acoustics and sounds. So, to begin with what do you mean by acoustics.

Now like you have different branches of study, in a same way you have a branch of study called as the acoustics. So, for example electromagnetics, it is a branch of study of electromagnetic waves.

So, it is the reception generation transmission of electromagnetic waves. In the same way, we also have mechanical waves and the difference between electromagnetic and mechanical waves is that mechanical waves sometimes also called as elastic waves. They require a medium for propagation. So, acoustics is the study of the generation, transmission and the reception of energy in the form of mechanical waves being generated in matter. So, that is the study of acoustics.

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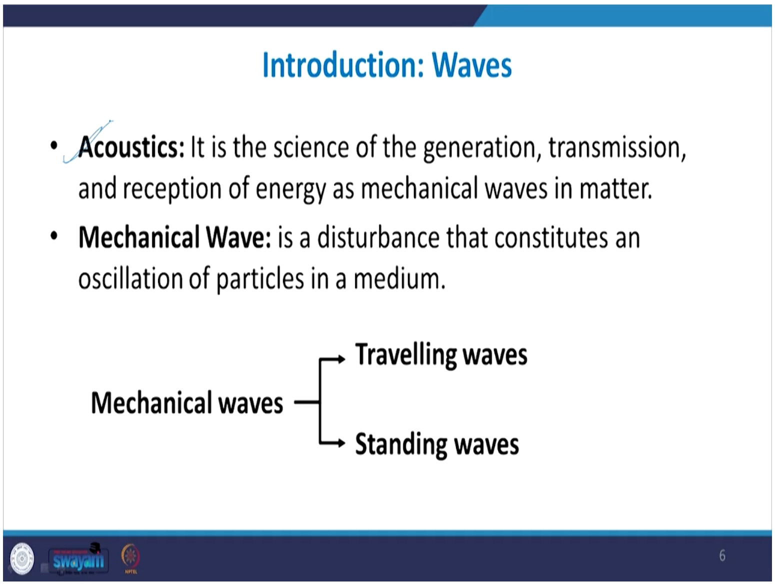

So, what do you mean by mechanical waves? So, as I said to you it is a wave which requires a medium for propagation to more specifically state. Typically the term wave the term wave means, it is the study of some form of disturbance. So, wave can either be for example let us say you are you have a typical you have got a instrument that is giving you the fluctuation in the voltage over time. So, here it is the study of some form of disturbance and what is this disturbance, it is the change in the voltage signal over time.

So, that is the study. So, that also becomes a wave in the, so in the same way wave is simply some form of disturbance and a mechanical wave is characterized by the disturbance which constitutes the oscillation of particles in a medium.

So, here the disturbance is typically that the medium particles they start to oscillate about their mean position and that disturbance and how does that disturbance propagate over space and propagate over time is studied as a mechanical wave. So, it is disturbance which constitutes oscillation of particles in a medium and this disturbance is studied over space and time. The mechanical waves can be divided into travelling waves and standing waves.

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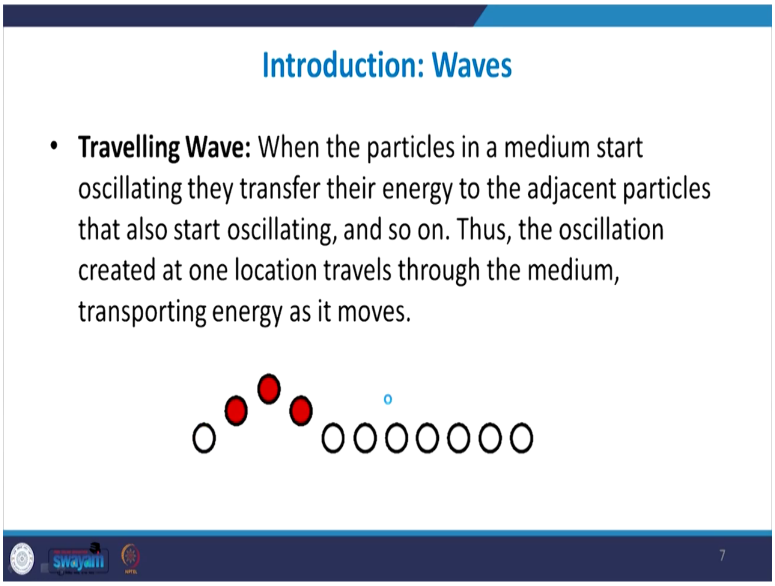

So, let us say what is a distinction between these two types of mechanical waves. So, travelling waves as a name suggested it is traveling. So, what is it mean is that when the particles in the medium, they start to oscillate, so let us say there was a vibrating surface. So, I will give you a very common example of a tuning fork.

So, let us say you have a tuning fork. You strike the tuning fork and the tongs they start to vibrate and so this surface is vibrating and very close to the surface are the air particles. So, when the surface comes in contact with air particles, the air particles will also start to oscillate right. So, this oscillation is begin at one point and it will be carried forward and that is why whether the tuning fork is 1 meters or 2 meters apart from our ear, we can hear its sound because the disturbance that was created at the point of source generation, it has been carried forwarded and is now being received by an ears and that is this and this disturbance we are perceiving a sound.

So, a typical travelling wave means it is a mechanical wave which varies over space and which varies over time. So, both space and time variation happens in a typical travelling wave. So, to the definition could be that when the particles in a medium starts oscillating, they will transfer some of their energy to the adjacent particles and when they, so when they oscillate they keep striking the adjacent particles. Some of the energy kinetic energy is transferred from one particle to another particle to the adjacent particle who then again start oscillating, they also strike their neighbours and then henceforth their energy is transferred to the neighbouring particles and so on and this energy or this kinetic energy keeps travelling.

So, the oscillation that was created at one location of finely travels through the medium and it transports a energy as it moves. So, this is a typical travelling wave.

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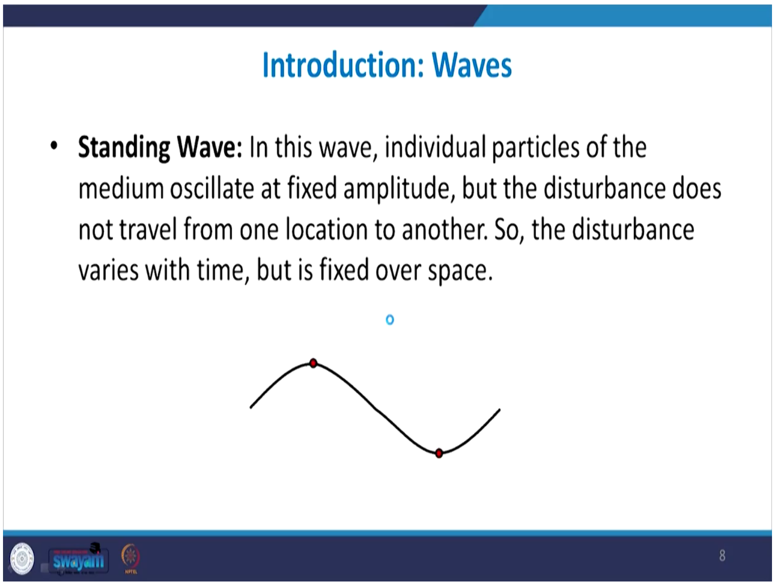

But what do you mean by a standing wave? It is a mechanical wave that varies over time, but does not vary over space. So, here the energy from one point is not being distributed or transported across other point in space. So, there is a variation in time, but no variation in space. So, the weight is defined is that in this wave individual particles of the medium oscillate at fixed amplitude, but the disturbance does not travel from one location to another. So, the disturbance actually varies with time, but is fixed over space.

So, this is the typical animation of a standing waves; as you can see here every particle within the medium is oscillating, but it is not being carried forwarded in space and a more detailed discussion of the standing wave will be done when we study about modes and resonance.

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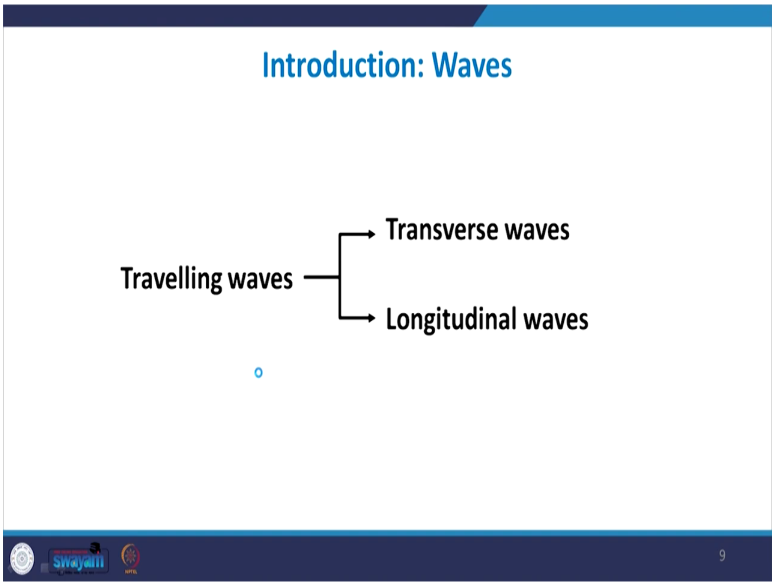

But in today's lecture and from now on we will be discussing about travelling waves because they are the most common waves and it is the travelling waves which are responsible for reception of sound because to receive sound or to perceive sound, we need the waves to carry the acoustic energy from one point to ears.

So, it is a travelling waves which are responsible for sound. So, travelling waves are divided as transverse waves and longitudinal waves.

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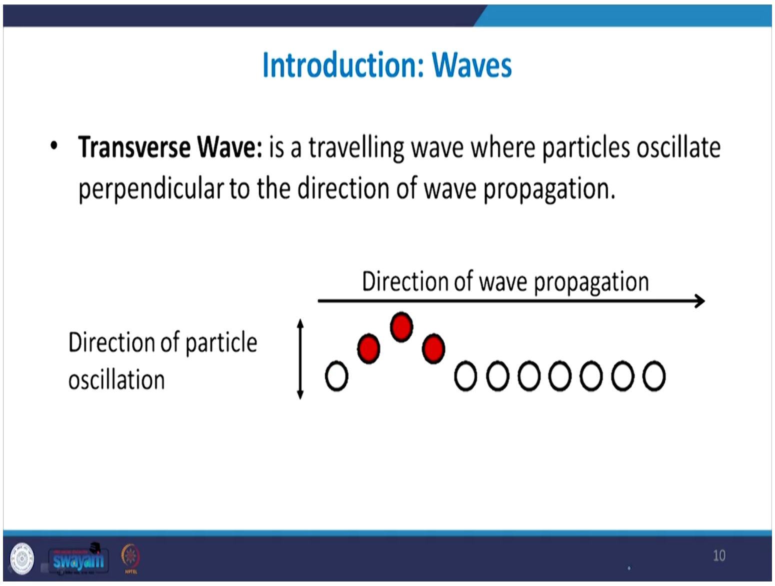

What are the two types? So, it is very clear from this animation here. So, here when you have when the particles are oscillating and they transporting the energy, so the direction in which the particle is oscillating here is up and down or the vertical direction, but the energy transport. So, here the red dots indicate the particles with high energy and high displacement amplitudes. So, this is lot of like the disturbance being created. So, the disturbance that is being created here at this point, let us say begins here, then it is carried forwarded till this point.

So, as you can see the direction in which the wave is propagating or the direction in which the disturbance is being transported is horizontal, but the individual pass particles they are oscillating in vertical direction. So, that is a transverse wave.

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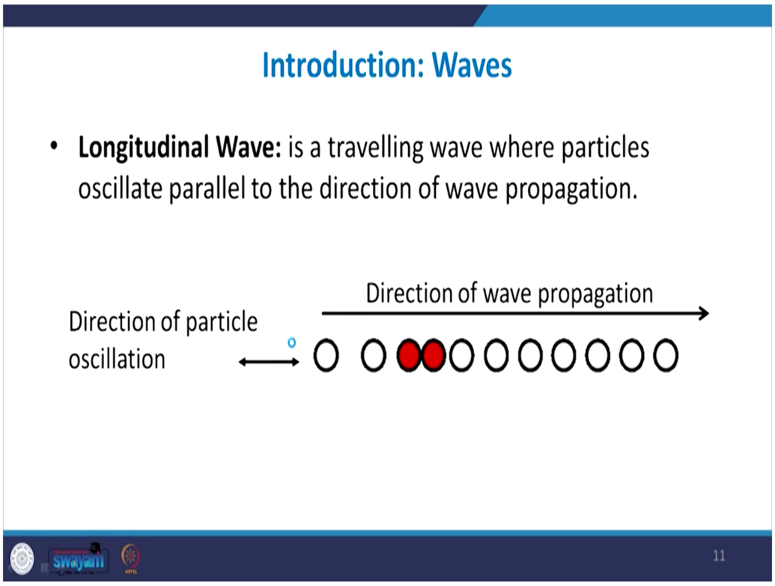

A longitudinal wave is where so here as you can see the individual particles they oscillate about their mean position in a two and four direction horizontally and the disturbance created here then starts to carry forward from extreme left to the right again in the horizontal direction. So, both the direction of particle oscillation and the direction of wave propagation is the same and that happens in the longitudinal wave. So, they are both parallel to each other.

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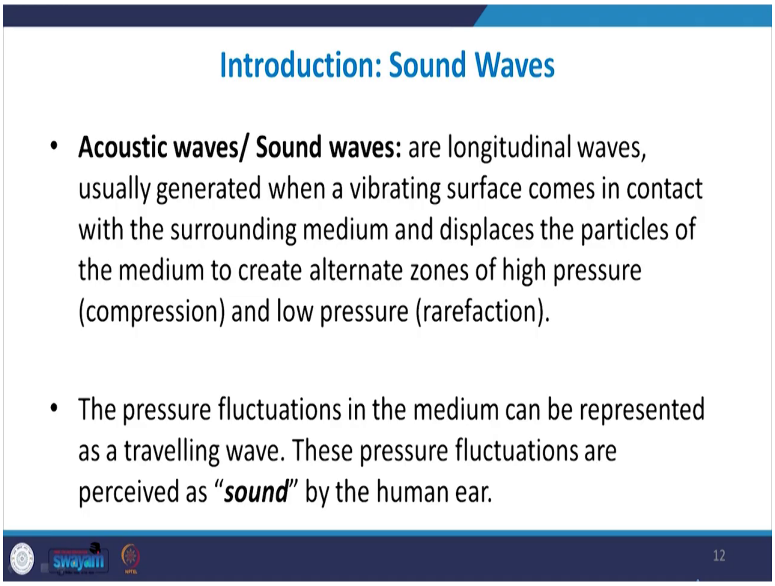

So, what are sound waves now? Sound waves sometimes also called as the acoustic waves. These are longitudinal waves which I usually generated when you have a vibrating surface which comes in contact with the surrounding medium and it displaces the particles of the medium to create some alternate zones of low pressure and high pressure or the alternate zones of compression and rarefaction.

So, as I told you before the example of a tuning fork, so when it is stuck the tones will start to vibrate and this vibrating surface is coming into contact with the surrounding air particles and due to the vibration.

So, let us see if I show it here. So, let us say my hand is starting to vibrate. So, it will touch the air particles and when the air particles come in contact, it will push the air particles away and then when it goes back it is again going to displace it in the other end. So, when it pushes the air particles towards it, so the air particles they are going to compress because suddenly it is pushing them and therefore, they are compressing, you can say a temporary zone of high pressure is created because of particles they are compressing.

And then when it pushes apart, suddenly the particles they will enlarge and a zone of low pressure will be created or the particles they will spread apart. So, the zones of high pressure and low pressure is what then gets transported throughout the medium and I will quickly show you an animation which will make this phenomenon even more clear. So, these pressure fluctuations to note is that these pressure fluctuations in the medium, these are a these can be represented as a travelling wave and as I told you that a wave is simply some disturbance over space or time.

So, we can study how does this pressure, then the this small change in the pressure when the particles they come together and they go apart, then they come together and they go apart, this minute change in pressure how does it vary over time in space. If we start studying them, then that can be called as a study of the sound wave and it is these pressure fluctuations which we perceive as sound by the human ear.

So, that is what we call as sound or the small variations in the pressure of the medium in which our ear is our ear is mostly in the air medium. So, it is a small pressure fluctuations in the air medium.

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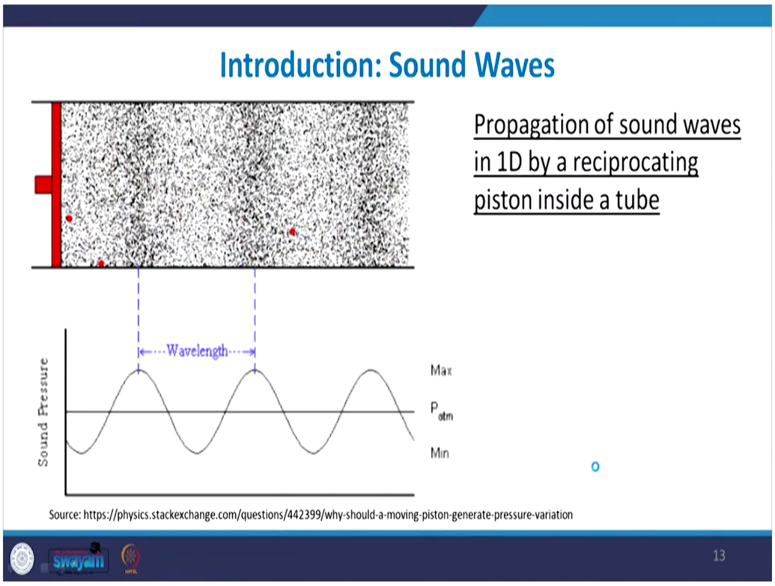

So, here from the animation you can get a more clear image. So, here you have here is a long tube is there and a piston is at one end and the piston is set in two motion and it vibrates to and fro. So, here I have shown a very slow animation to make the things more clear, but otherwise the fluctuations are pretty fast. So, I have shown you a slow animation here. So, as you can see as a piston moves towards, so it is moving towards it is pushing the particles together and a zone of high pressure is created and then as it is pushing apart, a zone of low pressure is created near the piston. So, the zone of high pressure and low pressure and so on. So this is where wherever the particles they are together, it is a zone of slightly higher pressure and the particles wherever they are apart is the zone of slightly lower pressure and this is being carried forwarded in space.

So, it starts to begin here when it vibrates, it pushes the particles and then it keeps carrying forward and this disturbance so, here the location where the particles are the closest together can be called as the in a waveform it can be called as the point of high pressure and where the particles are the most spread out together can be called as the point of low pressure.

So, as you can see here high pressure and low pressure has been mapped. So, this wave is being carried forwarded. So, this animation is a very helpful animation to see how this particular phenomenon can be represented in the form of a wave.

So, here this is the so here simply we have what we have here is the pressure fluctuation which is being carried forward. So, wherever we have higher zones, the particles whenever they are closed together we get the maxima and the particles whenever they are spread apart, it is the minima and then we have points in between.

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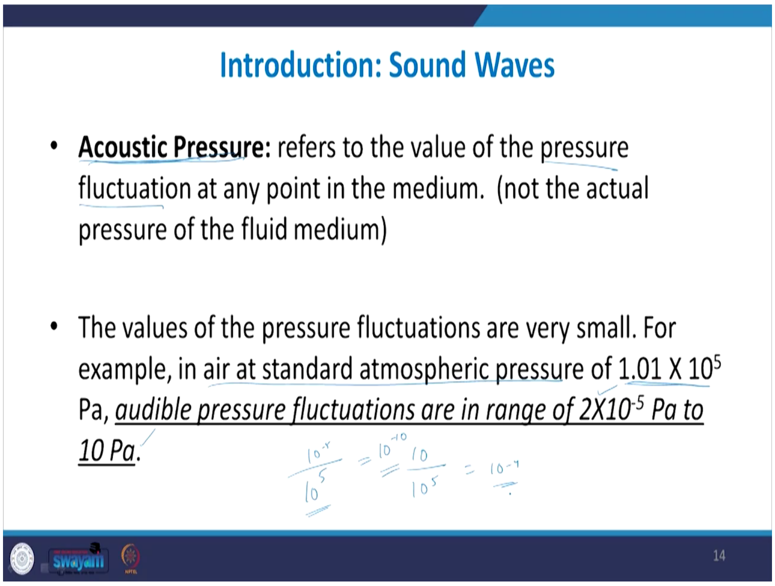

Now, to give you a little bit of reference here. So, acoustic pressure or the sound pressure typically does not mean what is the pressure of the air. The acoustic pressure or the sound pressure typically means what is that small change in the change in the atmospheric pressure due to this vibration. So, the particles they are oscillating to and fro and they are carrying the disturbance forward.

So, there is some sound, there is already a pressure of the atmospheric pressure of air and then on the top of it the particle is start to oscillate, so a small change will happen in the actual acoustic pressure and the sound pressure is that change in the atmospheric pressure. It is not the actual pressure of the fluid medium.

So, it is simply the pressure fluctuation. Now to tell you how sensitive the human ear is, so we know that the air at standard atmospheric pressure is 1.01 into 10 to the power 5 Pascal's. So, this is the typical atmospheric pressure and the acoustic pressure fluctuations that our human ear can hear.

They are in the range of 20 micro Pascal's to 10 Pascal's. So, usually so these are the ranges over which we can hear. So, which means that the overall pressure is of the magnitude 10 to the power 5, but even a 10 to the power minus 5 Pascal's of variation in this particular overall thing can be perceived as a sound. Similarly of variation of up to 10 and 10 to the power 5 can be perceived with a sound. So, this is 10 to the power minus 10, this is 10 to the power minus 4.

So, as you can see such a small fraction, even a small fraction of change of the order of 10 to the power minus 10 to 10 to the power minus 4 times the mean value of the pressure is actually being perceived a sound and it is this thing that we are studying. What is this small minute fluctuation in the atmospheric pressure? That is the sound pressure.

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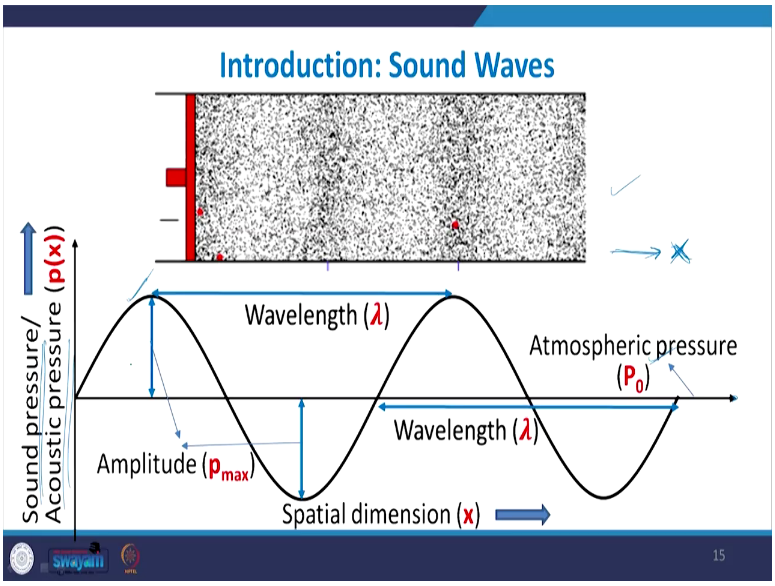

So, again if I use the same animation and the same example where a piston is sort of creating these zones of high pressure and low pressure, then as I told you that the sound pressure is a variation over space and time. So, I can study in both as a variation over space and time. So, here this is a typical example of a one dimensional variation. So, here we if this is the x direction or the x axis, then what will be the variation like? It can be represented in this wave fall.

So, here what we are studying in the vertical axis is actually the sound pressure which is also called as the acoustic pressure and I told you this is not the actual atmospheric pressure, it is actually the change in the atmospheric pressure. So, this mean line or the 0 line is the atmospheric pressure and then the variation over the atmospheric pressure is represented as a sinusoidal wave.

So, here a few parameters I will introduce to you. The distance usually in most of the acoustic processes, the fluctuations are very small and us and one of the simplest and common solution for this is a sinusoidally varying waveform. So, most of the sound waves, the common sound waves can be a sign it can be represented as a sum of sinusoidally varying waveforms. So, we only study about sinusoidally varying waveforms.

So, here this waveform is changing after a certain distance, so after a certain distance the waveform repeats it pattern and that distance becomes the wavelength lambda ok. And what is the amplitude? It is the maximum value of the pressure fluctuation or the maximum value of sound pressure.

So, this is going to be lambda, this is also going to be lambda.

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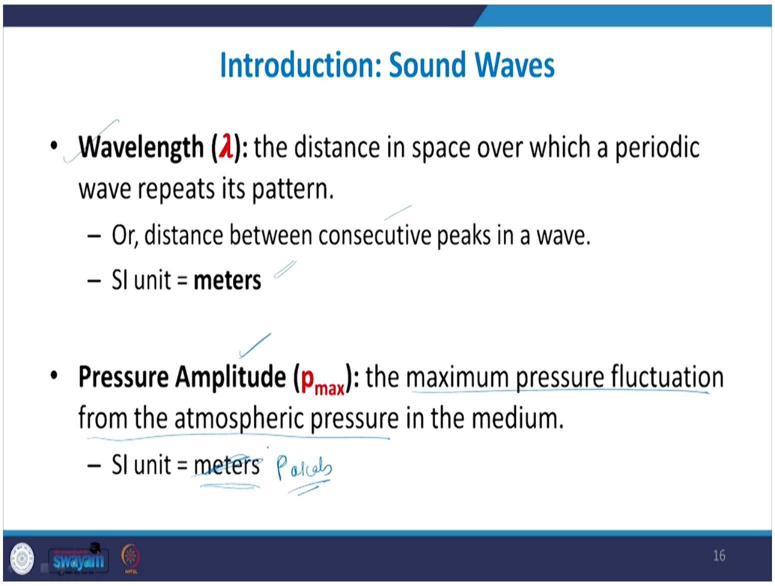

So, these are the two parameters; wavelength which is a distance in space over which a periodic wave repeats its patterns or the distance between two consecutive peaks and the units is going to be meters. The pressure amplitude is what is the maximum pressure fluctuation from the atmospheric pressure. So, let us say if its atmospheric pressure is 10 to the power 5 Pascal's that is the atmospheric pressure and the waveform is, so that it varies from 0 to 1 Pascal's, then 0 to 1 Pascal's and so on.

So, 0 to 1 Pascal's to minus 1 Pascal's to 1 Pascal's and then again to minus 1 Pascal's, then the magnitude of the maximum fluctuation becomes 1 Pascal. So, that is the maximum pressure amplitude p max.

Again represented in SI units as meters, sorry it is represented as Pascal's in the SI unit ok.

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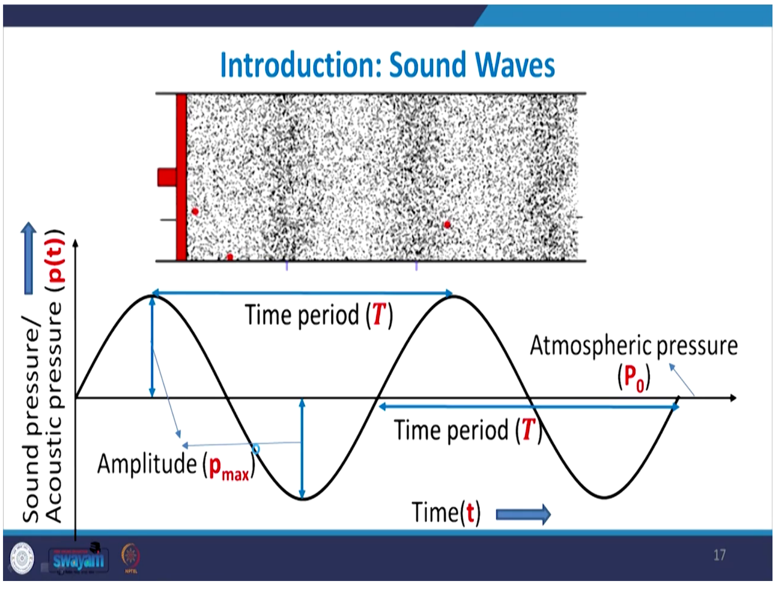

Now, we studied about the waveform as the variation in space. So, what we did here was that we froze the time. So, let us just freeze the time and see how the waveform is varying over space. So, you start from here. So, this waveform it creates, it goes down, then it keeps propagating forward, then you can study the same wave as a variation in time. So, you freeze the space.

So, let I while freezing a space what I mean is that let us just take one point. So, when I freeze the time which means that I am taking just one point and seeing how it is var sorry I am taking I am just freezing the time means I am just taking a snapshot of this particular animation and seeing how the waveform is.

Now, I can also freeze the space which means let us take one point and see how that one point varies over time. So, let me start here, let me take a point very close to the piston here this point. So, as you can see let us say a time T equals to 0 it begins. So, let us say this is the instant of time T equals to 0.

So, suddenly you have a maximum minima maxima minima and so on. So, it is also following the same sinusoidal pattern. So, it can also be represented in the same way, but along the time. So you will have a sound pressure and an amplitude and the amplitude max will be the same as the pressure amplitude max when represented over space, but the pattern is also repeating over time.

So, this distance over time or the length of time after which the wave is repeating its pattern is called as the time period. So, this is a new parameter and all the other quantities are the same.

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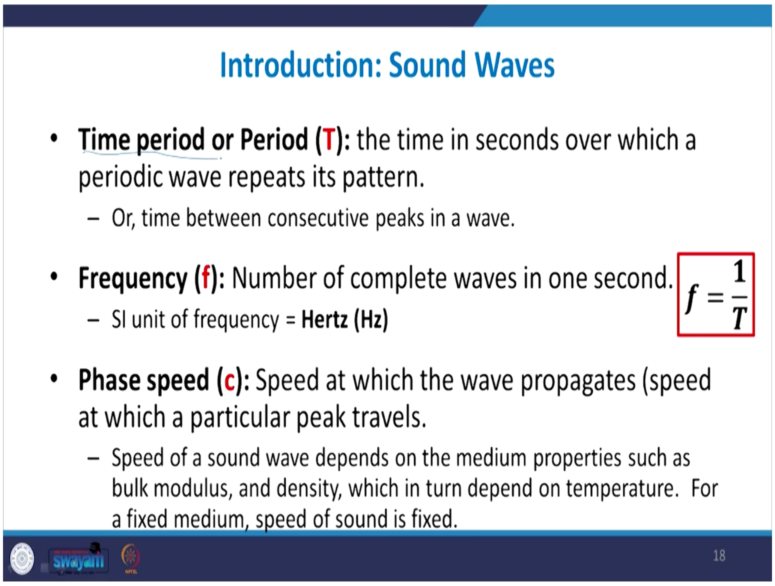

So, when we represent the wave as the variation over time, we get a new parameter which is called as the time period or the period of the wave. This is the length in time or time in seconds over which the wave pattern repeats itself ok or it can also be called as a time between consecutive peaks in a wave. What is frequency?

It is the number of complete waves that are generated in one second. So, now you see that suppose a wave is taking total T time to complete 1 cycle and f is the number of cycles generated in 1 second, then by the typical definition itself we get f as 1 by T.

So, let us say a wave takes 5 seconds to they it takes 5 seconds for 1 complete wave cycle, then within 1 second how many waves will be there? There will be 1 by 5 waves. Similarly a wave is generated and takes 0.5 seconds. So, in half a second we get one full wave. So, in 1 second we will get 1 upon half which is total 2 waves in 1 seconds. So, frequency is the reciprocal of the time period and the unit for this frequency is Hertz or Hz and you will be encountering this unit again and again in this course because frequency is a very important component or a very important parameter specially for noise control and it is measured in terms of Hertz.

When we have something called as the space the phase speed or called as the speed of the sound, it is the speed at which the wave is propagating and the speed of the sound depends on the medium property such as the bulk modulus density which in then turns depends on the temperature.

So, if you have a given medium given fluid medium maintained at a fixed temperature and pressure, then the speed of the sound for that fixed medium will remain fixed throughout that medium, but as the medium changes let us say you increase the temperature or you change the density or the bulk modulus of the medium, then with this change suddenly the speed of sound will change ok.

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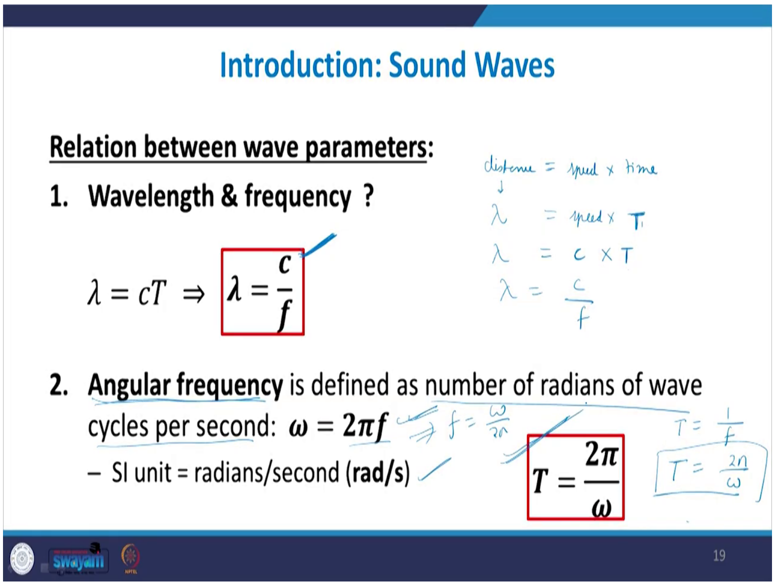

So, let us derive the relation between the different wave parameters. So, what should be the relation between lambda and frequency? Now we know that distance is equal to speed into time and what is the time taken by? So, distance is speed into time. So, let us take let us say what is the total distance covered by one full wave cycle. The total distance which is covered by one full wave cycle is lambda and what is the time taken to cover one full wave cycle? The time taken to cover one full wave cycle is by definition the time period T, then lambda is going to be c which is the speed of the sound multiplied by T and we know that T is equal to 1 upon f. So, it becomes c by f.

So, this is a very important relationship. Once again this is lambda is equal to c by f. This is how the wavelength and frequency are related within a medium which has a fixed speed of sound and as you change the medium, again c will change and accordingly lambda is going to change because frequency will remain fixed if the source is fixed, again a new parameter.

Another important parameter is the angular frequency which is the number of radians of waves cycles per second.

Now the number of wave cycles per second is f. So, the number of radians will be in one full cycle we are covering 2 pi revolutions because it is a sinusoidal waveform. So, it will be 2 pi f represented as radians per second. So, what is the relation between T and omega? So, how do we get relationship? It is very simple from the definition itself.

So, T is 1 by f and f is omega by 2 pi from here. So, you put the value of f in terms of omega. So, what you get is omega by 2 pi. So, this is again an important relationship. So, with this I would like to conclude this very first lecture. We studied about what is a wave and what are the various parameters associated with a typical graphical representation of the wave. So, see you for the next lecture.

Thank you.