Basics of Noise and Its Measurements

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Lecture - 02
Vibration versus Waves

Hello again, welcome to Basics of Noise and its Measurements. This is the first week and the second module of this course and what we are going to cover today is this; what is sound?

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Before I discuss in detail as to what is sound, what is the meaning of sound? I would like you to look at this particular video. This is about minute and half long video and please look at it and think about it as you watch it, as to what is happening and why is it happening.

So, what you see in this video is that you have a glass, glass which can be used to drink some juice or wine or some drink, and the glass is empty as you see it. All you are doing in front of that glass is playing a particular frequency, subjecting this glass to a particular sound of a particular frequency. What you see is that at that particular frequency if you increase the amplitude of the sound, the glass starts vibrating significantly. Because glass is very brittle it cannot observe a lot of vibrations, so even small amplitude of it is vibrations causes after a certain amount of time for the glass to explode or crack.

Just wanted to get you into this whole area of acoustics, and think about it as to how if you exposed let say a glass made of earth you know kulhad or something, if you know pottery and if you do the same experiment will you be able to accomplish the same goal or not, or if you use glass of styrofoam or paper will you be able to accomplish it or not so think about it. And maybe later in the course, I will explain that what works for glass made of glass may not work for paper cup or a paper glass or a styrofoam glass or a glass made for earth and why. So, that is all I wanted to show in context of this particular glass.

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And now, what we are going to discuss are two important words. The first word is Vibration, and the second word is a Wave. And, what I would like you to understand is a very clear sense of what is the meaning of vibration, and what is the meaning of this term called wave because in context of sound, both these terms are important. We say that sound is a particular type of a wave, but then these waves are generated when some particles are vibrating. So that is what I like you to show you.

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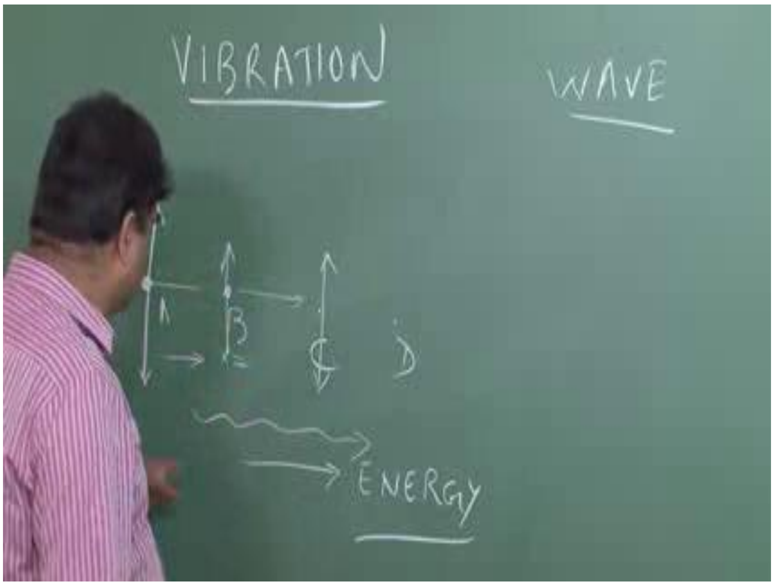

The first term is vibration. What happens in vibration is that, if you have a particle, whenever we are talking about vibrations we start with this notion of a particle which is vibrating. So, you have a particle and this particle may vibrate around its mean position. Let us say, this is the mean position. It may vibrate up and down or it may vibrate left and right or it may vibrate at some angle. So, vibration when we talk about it is about specific particles moving up and down or back and forth or the sideways or whatever, about a particular mean position.

Now, if there was just one particle then there would not be any wave. Wave is generated when we have more than one particles, if we have more than one particles and if all these particles are somehow physically connected, then if one particle vibrates up and down and because all the white particles are physically connected then the particles which is standing or sitting next to this particle the original particle which was vibrating that gets excited.

The energy gets transferred from particle A. Let us these are different particles, so energy gets transferred from particle A to B, so this also starts vibrating maybe a little later. Once particle A has started vibrating, it takes some amount of time for energy to travel from point A to point B. So, you have transfer of energy in this direction, then once, particle B starts vibrating then again this energy; because B and C are also physically connected, so you have excitation of particle C. Again, it happens a little later then the point of time at which B started vibrating and so on and so forth. You have transfer of energy in this direction. This of transfer of energy is associated with this thing called a Wave.

Now, remember that particles are vibrating about their mean position, so it is not that particle A is moving to point B to moving to point C and moving to point D and so on and so forth. The particle is more less fixed at it is mean position it is not moving from one mean position to the other mean position. But, what is happening is that energy is traveling, and it can travel very long distances while particles can remain vibrating about their mean positions and not shifting their mean positions. So I will show you an illustration of the same phenomena in this video.

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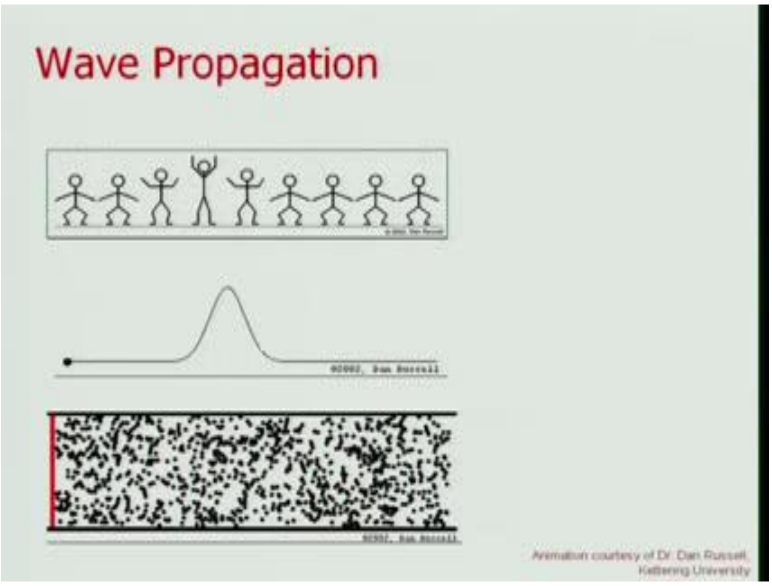

Now, these are some animation pictures courtesy of Dr. Dan Russell, Kettering University. These are very nice animations. Let us look at the animation which is on the top. So what you have is, number of persons let say in a stadium, and what happens is that you have this person he or she gets excited by the sight of let say some game and the person stands up and sits down and else. And the excitement gets transferred from this person to the adjacent person a little later and so then the second person gets excited, and then that excitement or excitation gets transferred to the third person. So, all these individuals they are moving up and down in this case. They are moving up and down vertically about their mean positions, but the energy is getting transferred in the horizontal direction, if you can call it the x direction.

So, what you have seen here is that energy is getting transferred in the x direction or the horizontal direction, while the particles or in this case the people they are getting excited in the vertical direction or along the y axis. You have vibration of individuals, while the wave is exciting the whole. A fairly similar phenomenon is happening to this long string. Let say the string is free at this end, and I am exciting this string at this origin so what happens is first this particular point get excited in the vertical direction, then a point which comes a little later and so on and so forth. The transfer of energy again happens along the horizontal direction, while the motion of the particle or particles which make up this whole rope or the string is in the vertical direction.

Again, as I mentioned earlier if these particles were not mutually connected then this transfer would not happen. It is important that for a wave to propagate, the particles have to be physically connected to each other otherwise the wave could not propagate. So that is what we see in this video. And you have may have learnt it in your earlier classes or in the collages that if particle motion is at 90 degree direction, in this case in the vertical direction and the relative to the direction of the wave then that type of vibration or that type of wave is known as the Transverse wave. It is known as transverse wave because the direction of propagation of energy is in the direction with respect to the motion of the particle.

Now, let us look at third situation, the third picture. What you see here, is a red piston and this piston is moving, it is getting disturbed slightly and the whole tube is filled up with small particles of air or say dust or smoke or something. So, what happens is that when this piston moves a little bit forward it pushes the air particles which are just touching the piston and these our particles also move a little bit further. But once the piston moves back then these particles come back to their original position. The particles are moving a little bit further forward and then go back to their original position, but as they move forward and then go back to their original position they also disturbed particles adjacent to them. And the particles which are adjacent to these particles, they disturb particles further down string and consequently the disturbance or the motion energy or the kinetic energy of these particles it travels in the horizontal direction or in the x direction. It just happens in this particular example.

The direction of motion of particles and the direction of the wave or the disturbance of particles or the energy is getting transferred in the horizontal direction or in the x direction. Because here, the motion of the particle and transfer of energy direction they are both aligned this type of wave motion is known as a longitudinal wave. This is known as a longitudinal wave. Now, there is no reason to think that you can have only two types of waves; longitudinal waves or transverse waves. There could be all sorts of waves. But we before do that let us look at some more animation, and this is important.

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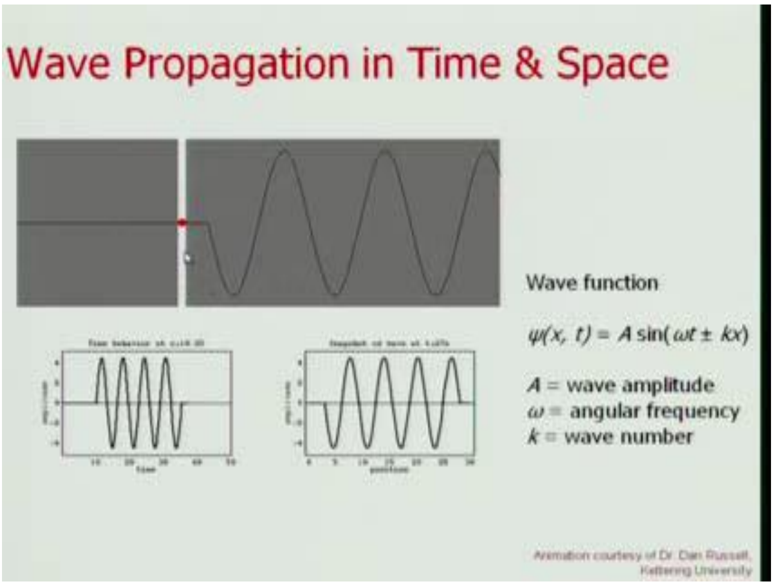

What we have seen here is that you have in the top portion of this picture. Let say, you have a rope which is initially static and then this point gets disturbed, and then what we are doing is that we are looking at the motion of this red dot, at this particular value of x. Let say horizontal axis is x and the vertical axis is y. So initially, the rope is fixed and it is not moving at all.

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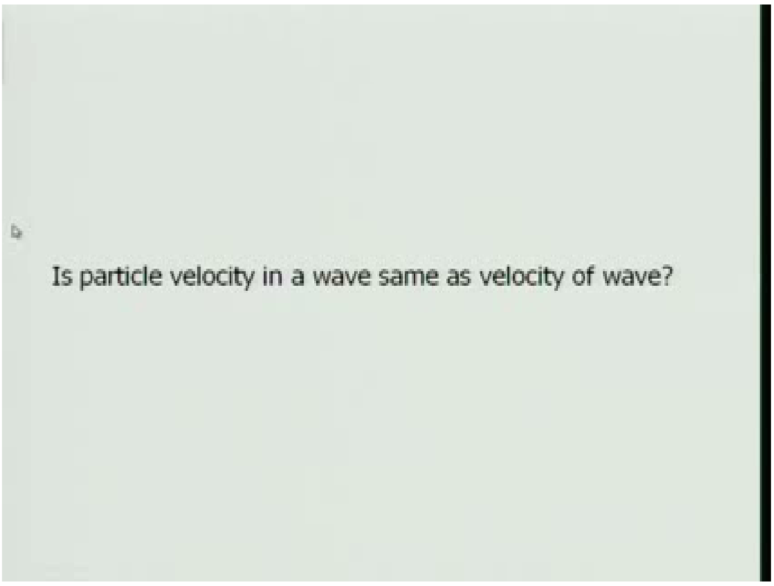

Then there is some excitation at this end. This excitation propagates, the particle gets excited and it keeps on getting excited and then the excitation of the rope stops. So after a while the motion of the particle also stops and everything will become flat. Now, what we are doing is, we are plotting two graphs. The first graph, we are going to plot is about the motion of this particular particle along the time axis. In the x direction, we are plotting time and in the y direction we are plotting the physical amplitude of the particle.

The motion, how much our distance by which the particle moves up or down? So initially, particle is not moving and then all of a sudden starts getting excited and moves up and down, so it keeps on moving up and down and then again it becomes static because it is not getting excited any more. This is the first plot, which we are looking at and that is the time behavior of the particle at a particular value of x. In this case, the value of x correspondence to the location of the point and that is in this case number 10.25 centimeters.

The second thing what we are going to look at is, so initially we just looked at a particular point. Now, what we are going to look is a picture of the whole wave at a particular time. On the x axis we are going to plot the position, position means the value of the x coordinate for the entire rope and on the y axis we are going to plot the amplitude of each point on the rope but at a given time. So initially, everything is flat and then we are taking a picture of the whole rope at time is equal to 27 seconds and then what we see is that initially when t was 0 everything was flat, but the time t is equal to 27 seconds we take a picture and the picture looks like, we will see it here, it looks like this you know so it is up and down. This is frozen in time and this particular picture is frozen space. So what typically we express these two behaviors in time as well as in space in terms of a wave function.

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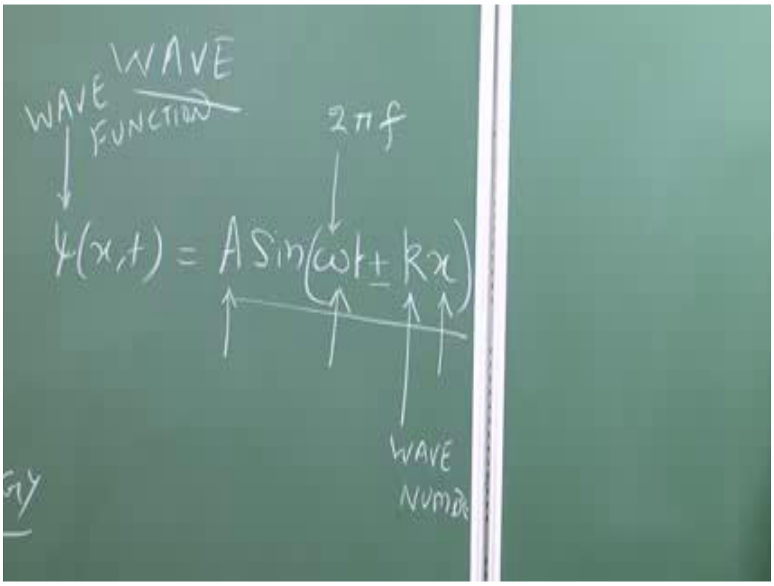

And that is an explained here as sin omega t, I just want to make sure that I do not get different terminologies. This wave function and this is what it looks like at least in the context of the motion of the rope which we were looking at. This is the amplitude of this wave, this is the angular frequency of the wave, this can also be expressed as 2 pi times f, and this is the position of the wave x is the position and this is known as the wave number. So, when we are talking about waves, we are not talking about motion of a single power point, but we are talking about motion in space as well as in time. So it has a time component to it and it has a space component to it.

As, I mentioned earlier there is no reason to presume that waves can only be of two types; longitudinal or transverse. Those are the types which we have read about in our B.

Tech or B.E programs, but there are several types of waves and what I will do is I will show you a picture of another type of wave. But before that there is this question, is particle velocity in a wave same as the velocity of wave? The answer to that is no. Wave velocity is the velocity of the propagation of energy how fast energy is getting transferred from point A to B to C to D and to E that can be significantly different than the velocity of the particle. In a lot of cases particle velocity is probably not as high as the velocity of the wave.

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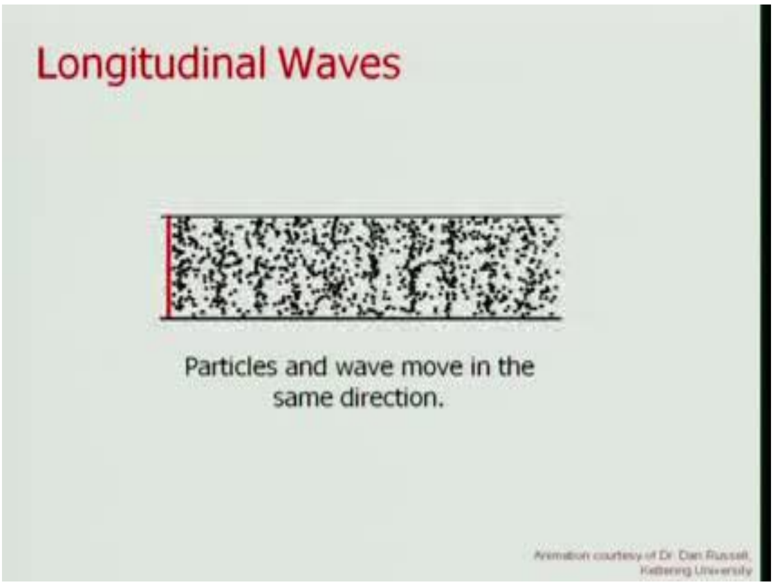

These are Longitudinal Waves, and here what you see is that particles and waves move in the same direction. Both of them are moving in the same direction, both are aligned, so they are longitudinally aligned.

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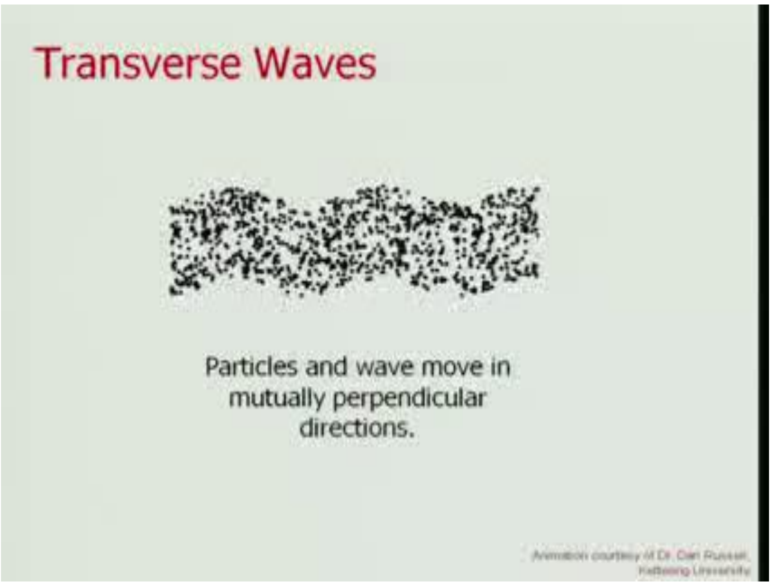

Then you have Transverse Waves. So, I can take sheet of paper and I can vibrate it like this one end, and as a consequence the energy gets transferred in the transverse direction with respect to the direction of the motion of the particles so that is why they are known as transverse directions. We have these waves, were particles and waves move in mutually perpendicular directions. Then you have a third type of wave.

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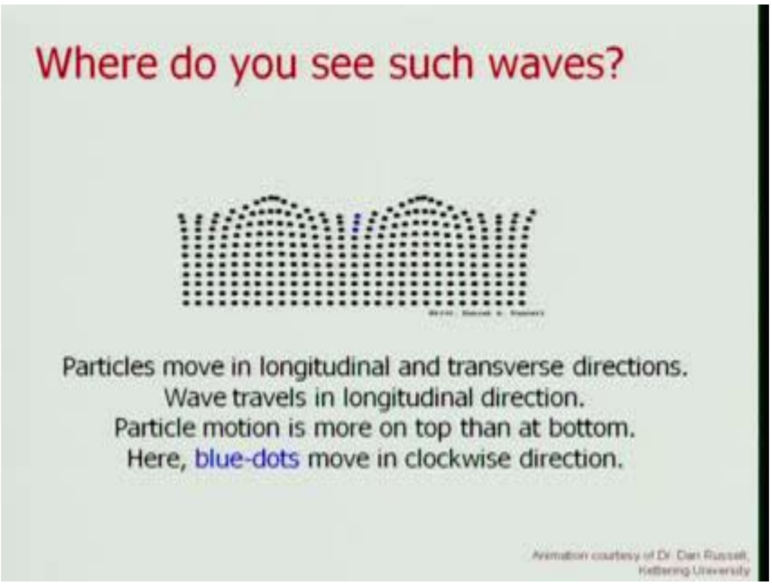

And, what you see here is a bunch of dots and you have focus on the motion of blue dot. What you see is that the blue dot is moving in a clockwise direction. It is not moving in the longitudinal direction or the x direction, it is neither moving in the vertical direction nor the transverse direction, but it is having motion which is circular in nature. Then there is another blue dot below the top dot and that particular dot is also or that particular particle is also moving in a circular way. What you see, if you observe carefully as you keep on going down from top to bottom all the particles are moving somewhat in a circular way, but as you keep on going down further down towards the fixed end, the amplitude of the motion of the particles or the radius of the circle which is covered by the particle, that particular radius it keeps on shrinking. So the amplitude of the motion keeps on going down.

Now, these types of waves if you think about it you would find in water. Suppose, you take a bucket and fill it with water and make sure that water is stationary and you drop a piece chalk in it, in the center. Then you will have these types of waves generated. Once again you will see that, in this case the particles are moving about a particular mean position, but the energy gets transferred in this case it is getting transferred readily outwards especially in water waves it is a radial transfer of energy. So, these are water waves.

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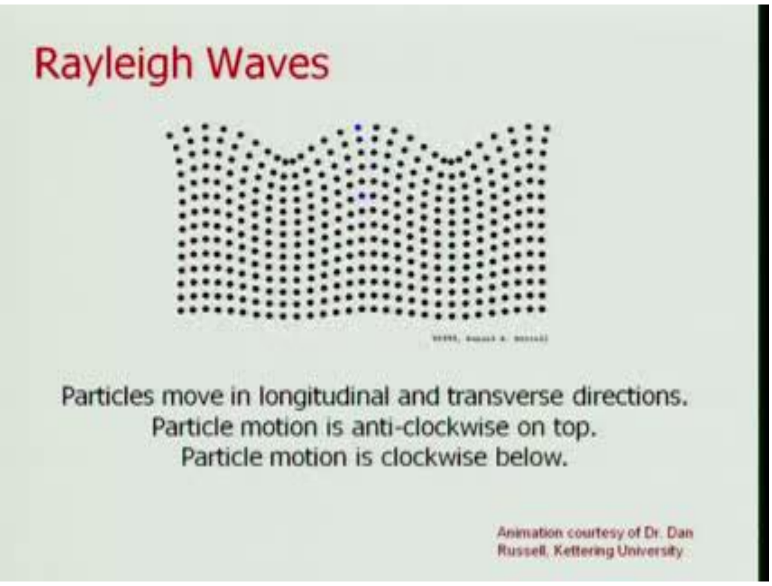

Then this, another wave and this is somewhat similar but also different in a very specific way then the waves we just now saw. These waves are known as Rayleigh Waves. Look at the motion of these two particles which are colored in blue, so you have the top particle and it is moving like this that is in an anti clockwise direction, and the amplitude is let say something. Then you have this other particle which is further down into the material and that is moving in the clockwise direction. You have one particle moving in an anti clockwise direction and another particle moving in the clockwise direction.

And you see the same type of phenomena happening for across the whole band of this material for which we have plotted the particles. These types of waves are known as Rayleigh waves. Once again, the energy transfer is happening from across the whole material, but the particles are moving either circularly in a clockwise way or in an anti clockwise way about their mean positions. So, these types of waves are known as Rayleigh waves and here you can interpret it is that they are moving in longitudinal as well as transverse directions simultaneously, but some particles are moving clockwise others are moving anti clockwise. The once which are on the top or the free surface they have larger amplitude of motion, the once which are at the bottom they have somewhat lesser amplitude of motion. So, that is what these waves are about.

So, now that we have seen different types of waves, not necessarily all sorts of waves. Now, let us think about sound waves. So, what is sound?

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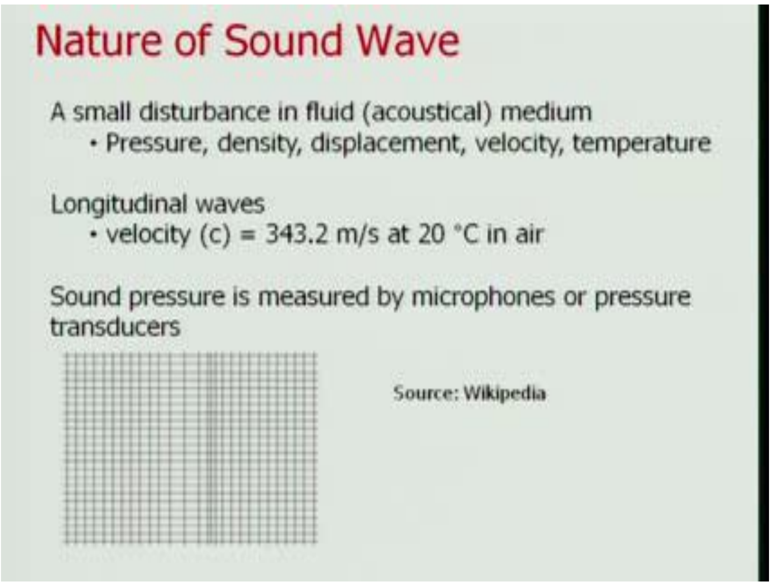

It is a small disturbance in a fluid medium. If you have a fluid medium which is at rest, let say I am standing in this room and there is no sound in the room and I am standing still air is not moving at all then there will be some pressure of air in the room, and if there are standard conditions then the pressure of the air will be one atmosphere which will be approximately 101 kilo pascals. Then I make a sound, so initially there is no sound, no disturbance in air, air is not moving, all particles of air are not moving. Then I talk or I do tick and then because of this sound there is a pressure fluctuation in the pressure of the air. So that is what physically sound represents, it represents a small disturbance and please be aware that we are talking about small disturbances not large disturbances. Small disturbance in a fluid medium and this small disturbance cause fluctuations. Again, these fluctuations are small, it causes fluctuations in pressure, it causes fluctuations in density, displacement, velocity and temperature.

This is what sound physically is. So that is what is shown in this picture down there. You have a medium, and this particular medium is getting disturbed at the left end and as this gets disturbed the disturbance moves to the right side and this type of transfer of energy in air due to longitudinal waves is referred as sound. If we have to measure this sound, it essentially means that we have to measure these small pressure fluctuations. We should have an instrument which is fairly sensitive to very small pressure fluctuations to measure sound and typically that is measured by micro phones.

The velocity of sound that is the speed at which the disturbance travels from point A to point B in air due to these sound waves is known as the speed of sound and at 20 degree centigrade it is value is 343.2 meters per second.

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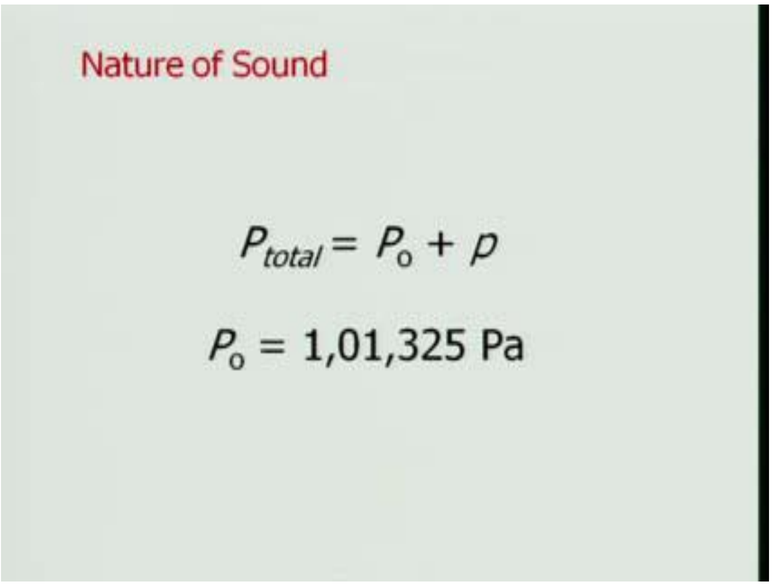

So, that is the nature of sound you have a total pressure, you have air, and in the air you have ambient pressure P naught which is so many pascals, roughly 101 kilo pascals and if there is no disturbance in the sound then that is the pressure of the air. Then you make a disturbance, when you talk in it or you create some noise or create some sound then there is an additional pressure, this pressure could be fluctuating it could not have a positive value or a negative value depending on the time.

You have a fluctuation in the pressure. So, the total pressure is P naught plus P, and this P is the pressure exerted due to generation of the sound. When we measure sound pressure we are actually measuring this particular P, we are not measuring P total, we are not measuring P naught we are just measuring this differential pressure with respect to the ambient conditions. So, that is once again the nature of the sound.

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These are different velocities. So, sound is a pressure wave, we have discussed that, and then what we have listed in this table are speeds of sound in different media. For instance, if you have air at 21 degree centigrade the speed is 344. In fresh water, it is 1480 meters per second, but if you go to ocean because of, it has some salt let say 3.5 percent salinity in this speed of sound goes up a little bit, so it goes up to 1520. Sound in human body, since we have made a mostly of water so sound propagation velocity in human body is fairly close to that in water and it is about 1558 meters per second. In wood, and concrete and mild steel sound travels much faster. So, in wood it is 3350, in concrete it is 3400 and in mild steel it travels really fast 5000 or close to 5 kilometers per second. And its velocity in glass also is somewhat very close to that in mild steel.

So, just wanted to give you a perspective different sound propagation velocity in different media and I think it is important to at least memorize or remember, at least two different velocities. How fast sound travels in air at room temperature conditions? About 344 meters per second, and how fast sound travels in water? It is about 1500 meters per second. It is important to internalize these two specific numbers, because in your daily life you may be using these numbers fairly regularly if you are actually involved with sound related measurements or noise related measurements. So, think about these and I think, this brings us to the conclusion of this particular module, and look forward to having you in the next one.

Thank you very much.