Energy Efficiency, Acoustics & Daylighting in building
Prof. B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

Lecture - 31
Noise & Acoustic Fundamentals

You know now we look into ventilation and I mean ventilation we finished. We looked into noise and some fundamentals of acoustics noise control designed for good listening and insulation. This is how we will divide them.

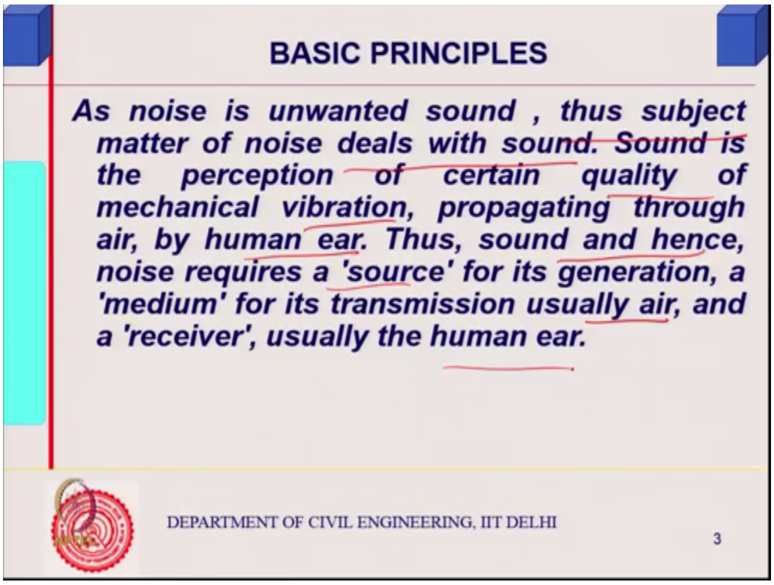
(Refer Slide Time: 00:36)

So, essentially if you see, basically what is noise? Unwanted sound, noise is basically unwanted sound and good listening was there for very long time, prehistoric times because an open empty theatres or the Ggreek dramas or even say Gupta age sudraka, you would have heard of Vishakadatta Navarathna in Vikramaditya. Sudraka has mricchakatikami. Do not know whether you have seen there a Hhindi movie based on that, but how it can be made a very good chattisghadi drama out of it, mitti ki gadi mricchakatikami.

So, you see the dramas were there, plays were there, dances in Indian, you know Bharath Natyashatram. So, all the dancers actually origins Indian classical dances originated from there. So, these were there good listening, good performance. These are very much there, but noise is a recent phenomenon in it. So, therefore, there are places like temple dancers or as I said dramas during the Gupta age in India or Romans, you know similar time, but obviously scientific knowledge is relatively recent and noise is a recent development because noise essentially we treated as a pollution. So, it is an wanted sound. We do not want them and it is largely has come from industrialization, industrial revolution advent of vehicular traffic and then, various kind of you know mechanization that would have gone in associated with. So, noise can decide. So, that is what it is.

Now, noise can prevent people from performing at their maximum capability. No, you disturbed. It is actually annoying. Many times there is a discomfort and can even be damaging to the health if it is a long term exposure, right. So, that is what it is.

(Refer Slide Time: 02:58)

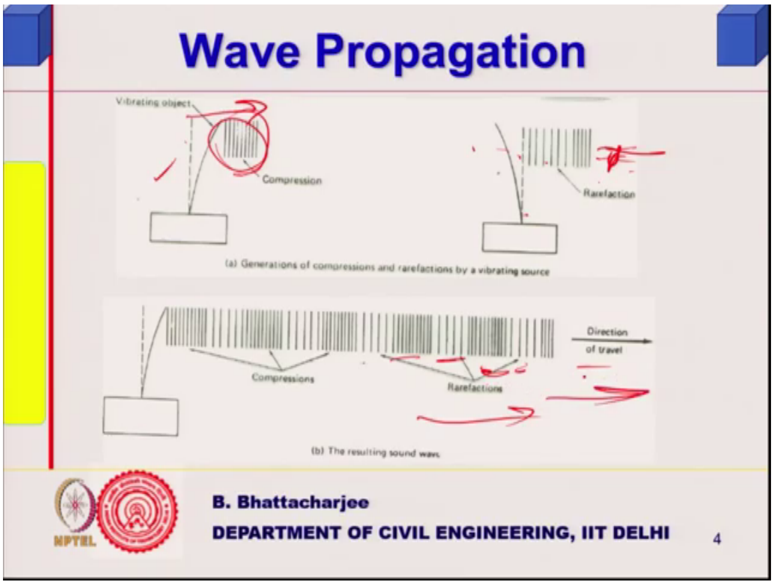


Thus, since it is unwanted sound, therefore it deals with this, with sound and of course, sound is perception of certain quality of mechanical vibration in air like we have sensory mechanism, we have been looking into thermal. You know the skin can feel the temperature, right visual of course. The eye is the sensory mechanism. Similarly, certain type of mechanical vibration in the atmosphere or an ear, around the ear you know that is we can pass it. So, sound is a perception of certain quality of mechanical vibration, propagating through air by you knows we perceive through our human ear. There is a sensory organ that is sound and hence, noise requires source for its generation because of the mechanical vibration.

So, you have to have some kind of a source that should generate and then, obviously mechanical vibration is essentially transmitted by motion of the particle about the mean position of equilibrium. Mechanical vibration you are talking of not electric field or magnetic field electromagnetic radiations. So, therefore, you need a medium where particle can particulate medium which can you know where through which energy can be transmitted through motion of those particles about their mean position of equilibrium.

So, this is usually which is just low story here and receiver is the human ear. So, that is what it is. So, sound is transmitted through the medium here and it is perceived by human ear sensory organism, you know sensory organ.

(Refer Slide Time: 05:00)



So, I have to have a source as simple source could be like a strip, like this is a strip which I can just pull on one side and release. So, when I pull on one side, I actually create a kind of a compression of the air there because the air was at equilibrium. I just pulled that strip and I created compression, but you know I have pulled it. The moment I release it, it will have a tendency to go back to its original state. So, that is here. So, then it moves there this strip like a scale or something like steel plate, steel strip you can think of you just pull it and yes, release it.

So, it is since you have given some energy, it will have a tendency to go back to its original state, but it goes further beyond and air here is compressed and when it goes back more than its original position, there is a kind of partial vacuum created. So, this is how you know this is the partial vacuum, then there is a compression, then if there is you know it goes to the extremity and again tends to return. When it returns, when it goes to the extremity, of course there is compression created. On the other side, when it returns, there is a vacuum on the other side and when it comes back, again here. Supposing it is moving sufficient you know displacement I have given in the beginning, then it moves.

So, again it will compress. First compression, then there is a kind of vacuum created because it has gone to the other side. When it comes back, again it will create again another compression and then, again you know and by this time this since this is already compressed and this air is not compressed here, air is not compressed. So, this compression will have a tendency to cause the air to spread in other words, the compressional level tendency to move when the next compression comes.

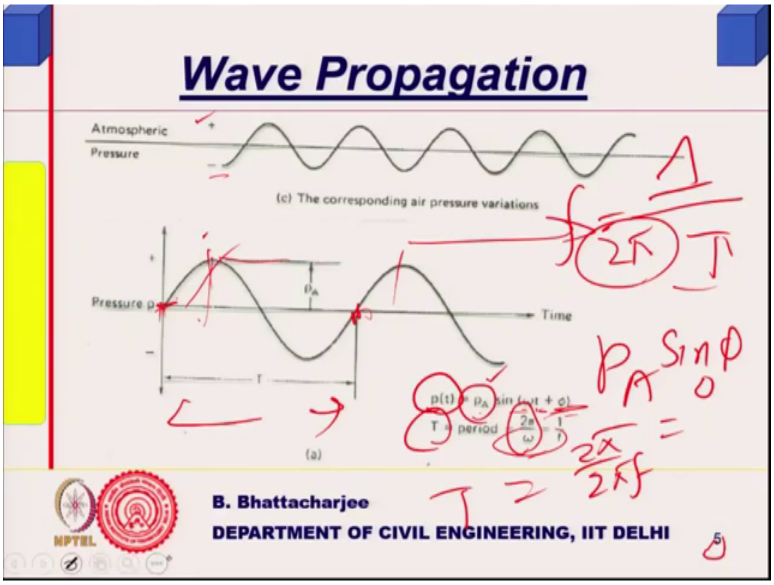
So, it is actually trains of compression, then what we call rarefaction or partial vacuum. So, I will~~l~~ have something like this. The first compression, then there is a vacuum and again it came back, another compression created, then a partial vacuum and if it continues to move in this manner, vibrate about it means position of equilibrium that it will create a kind of compression also on the other side as well, but I am showing only one direction one side. So, this is the direction of the movement of this compression and rarefaction. In other words, particle it start moving, air particle will start moving about their mean position of equilibrium.

They come close to each other and then, they separate out, right and it induces some similar kind of motion to the next set of air particle and when again another compression come, this pushes them apart. So, this strains of compression and rarefaction that travels and that is, what is sound we understand. Maybe you have done the same thing in school. So, that is what is you know sound and that is how this particulate motion when it comes and hits our ear drum, you know there is a sensory mechanism.

We just got a diaphragm. Ear drum will have a simple diagram there and this energy, this motion, this energy you can perceive it in certain manner through certain transmission mechanism from ear drum to the brain and brain perceives this motion and that is what we hear them as sound or distinct one sound from another.

So, if I look at it along x some space direction x direction, there will be negative pressure and positive pressure because compression and there is a partial vacuum. So, this pressure would actually keep on you know I can assume that it is periodic because first I had a compression, then there is some vacuum and then, there is again compression, but it is not stepped. It will increase gradually and then, decreased gradually pressure from compression.

(Refer Slide Time: 08:56)



So, therefore, I can think in terms of this kind of a periodic one because the compression would repeat itself after certain period of time.

So, we can think in terms of the pressure variation over and above atmospheric pressure superimposed over atmospheric pressure, right. Sound pressure is superimposed reverse atmospheric pressure. So, if I write pressure P, this is amplitude of pressure. We generally assume them to be sinusoidal or cosinusoidal and I can actually sum them up. If there is any other periodic one also, I can break. If I break it up into number of sinusoidal or cosinusoidal as you have done it earlier for temperature wave, therefore we can assume a pure tone or pure single you know frequency only or single periodicity.

So, when it repeats itself, the pressure peak and pressure starts from 0. Initially it was at 0 when I have given full displacement pressure was 0, right and when I released there is a compression. So, the pressure increases, it increases compression and pressure increases, then decreases so on. So, from zero pressure to again zero pressure, this is what we call as the time period.

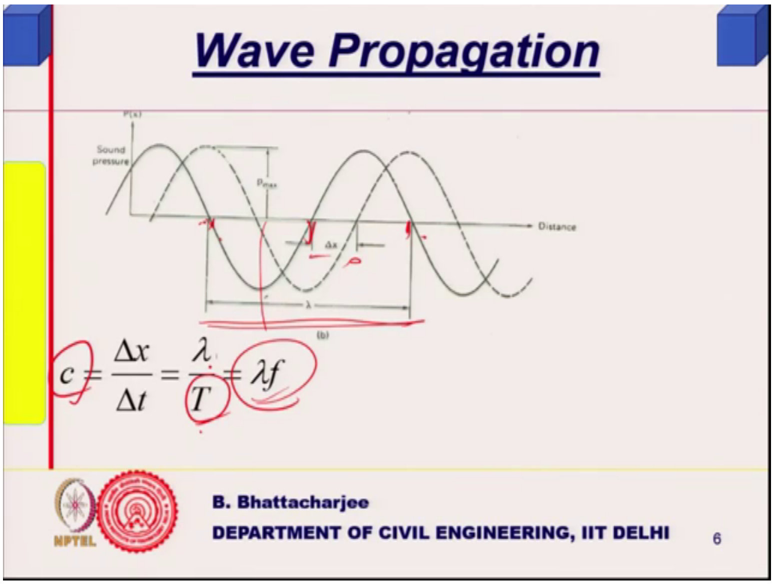
Same thing we did for temperature 24 hourly period. We said when the temperature repeats itself here, the pressure repeats itself. So, this is the time period, this is a time period, right. So, time period is nothing, but since we express them you know we can express this pressure in terms of time and we are saying that is periodic repeats itself after certain period of time, you can express periodic sine functions. So, we know our periodic.

So, you can write it like some amplitude PA plus some sine omega T plus phi, right. So, that means when T is equals to 0, it is equal to P sine phi, right. This is the case when T is equals to 0 PA say or or you know omega T, T is equals to 0. So, sines of phi. So, P is sine phi at T equals to 0. In my case if I take in this equals to 0 if I take it to be equals to 0, then in this case phi is equals to 0, but supposing the way would have started somewhere from there my datum is somewhere there, right then I would have at some value of phi.

So, this phi defines a starting point because at T equals to 0, where it was T equals to 0 where what was the value of the pressure and PA is the pressure amplitude. So, at this point if phi goes to 0 at T equals to omega T equals to pi by 2 omega T equals to pi by 2. I will have you know PA because cosine pi by 2 is equal to 1. So, this will be equal to PA. Now, period is therefore it repeats itself after T period and this can be you know because sine function repeats 2 pi sine 2 pi you know sine function repeats itself after 2 pi. So, I can write exactly the way we did 2 pi over omega or we call it since it is time, the number of such periods in unit time I call it frequency.

So, unit time how many periods that would be 1 by T f is equals to 1 by T. That we know because T is the time for one repetition. 1 by T is the number of repetition per unit time. So, T is and during this period of time, the sine function has gone from twice pi. So, angular frequency is omega. So, twice pi you can write it as twice pi by twice pi f 2 x pi f is equals to T because omega is the angular frequency. So, this is how we can just express pressure, right. We can express pressure in this manner, right.

(Refer Slide Time: 13:09)

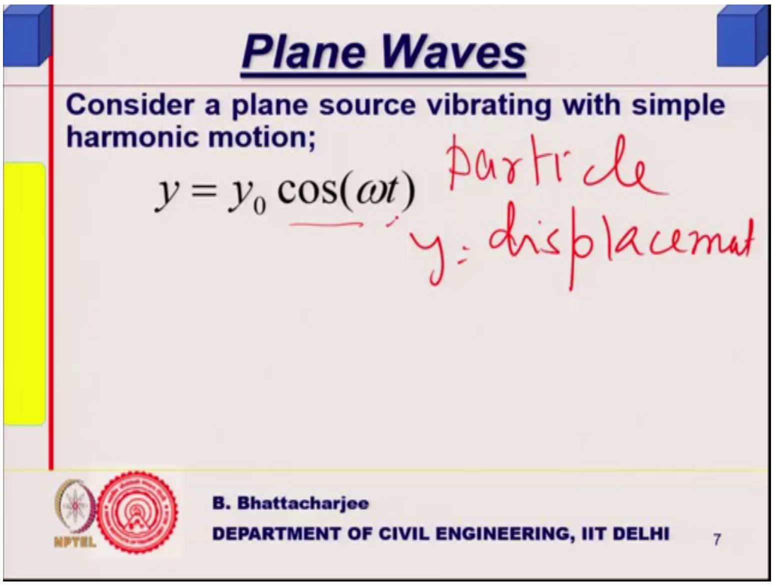


Sine omega T plus phi and if it has moved, if the wave has moved through a distance x, right to a distance x or delta x let me call it it has moved through a distance delta x during some period, some time delta t, then wave velocity will be given as delta divided by delta t, the wave has moved delta x divided by delta t, right.

So, c is equal to wave velocity. We denote by c velocity of the wave naught particle. Particle you know this peak how much the peak has moved over a period of time of delta t, that is delta x let us say. So, delta x by delta t and delta x is simply this. I call as wavelength that is the distance from this point to distance from this point to you know or may be the distance from this point, this~~ this~~ point or it is written here. So, when distance it travels the wave, travels during one time period or from same repeats itself, the distance after which it repeats itself for example, a compression to compression, compression peak to compression peak, this distance because as I said it moves as a train of pulses.

So, this distance compression to compression peak that I call as wavelength and during this period, during this distance, how much time were to take during this traveling from this point to this point, it is t time period because same time when this wave has moved at this position by this time here, again the zero pressure would have come back, right. So, lambda by t~~. So~~, simply c is equals to lambda into f because 1 by t is equals to f. So, this you must be knowing. So, for velocity wave velocity is equals to frequency multiplied by the wavelength. So, we define wavelength in this manner time period in this manner.

(Refer Slide Time: 15:12)

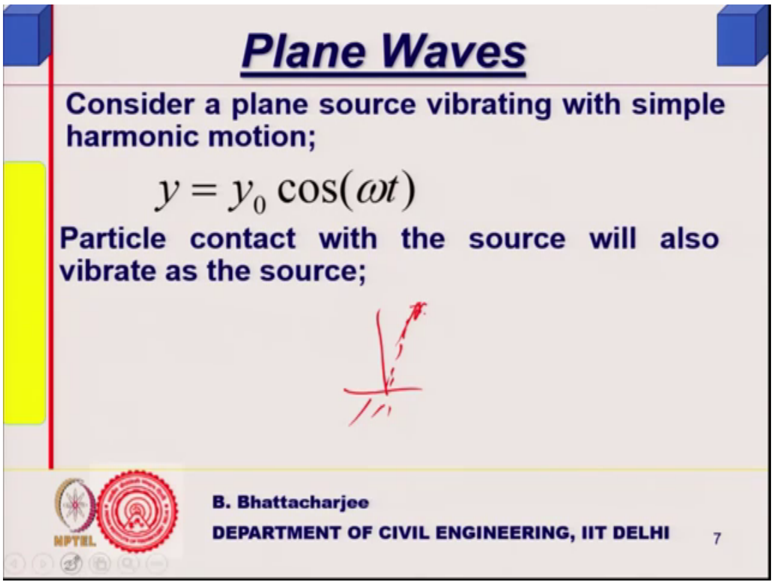


So, we consider plane wave for simplicity. Most of our cases we can treat to the plane wave which is basically this is what we call simple harmonic motion repeats itself. You know it is periodic repeats itself after t time period and by the time it travels through a distance lambda during the t period. So, this is, what we call a simple harmonic motion, right and see what about the particle displacement. Let me denote particle displacement by y particle displacement vertical displacement y y is particle displacement, right.

So, when time was zero, right I have already given a displacement at time 0 because I have given a displacement and release it. So, we actually went to its maximum displacement at time equals to 0. So, then it should be a cos function because cos 0 equals to maximum you know 1. So, y is equals to y 0 cos omega t. So, if I am defining pressure as PA sine omega t, right the displacement will be y into y 0. Y0 is the maximum displacement or amplitude of displacement.

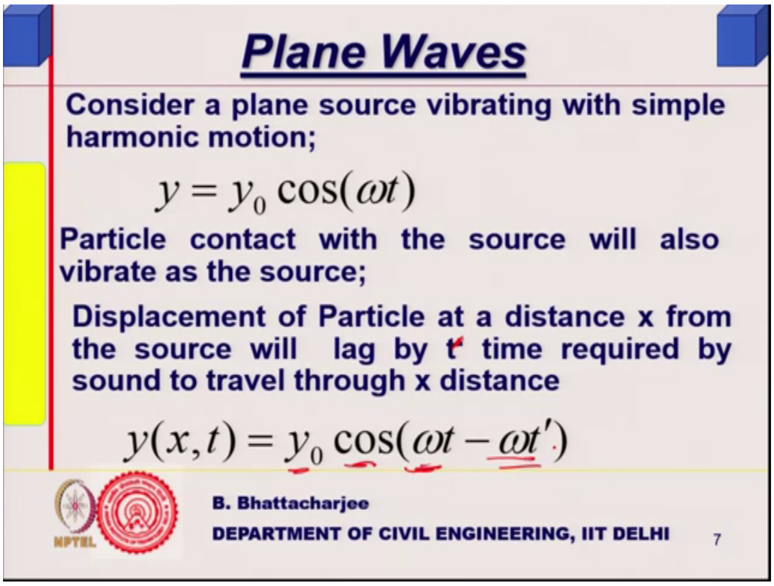
So, particle contact with the source will also vibrate as the source.

(Refer Slide Time: 16:42)



So, I gave the source this displacement. So, particle that is very close to the source will also vibrate with the source itself. Same diagram earlier you know I had this one. So, if this moves somewhere there, the particle close to this one, this one would have moved together with the source itself.

(Refer Slide Time: 17:08)

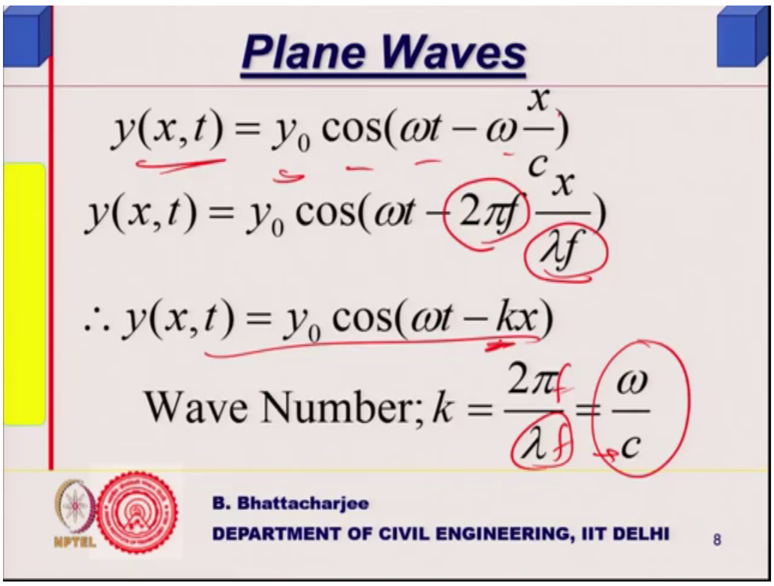


So, it would have had the same displacement as the source and then, displacement of particle at a distance x from the source will be then the particle which actually was you know particle movement has started from the source. Source initiated the particle movement. So, the particle starts moving from the source, then it travels because as you know when it goes back, there is an air friction and then again another compression comes in so, in the process this particle movement about their mean position now quickly along they start moving.

So, the movement of the particle some x distance away it would have been initiated t times earlier at the source. It would have been initiated t tends earlier with the source the train of pulses moves. So, first compression, it would have triggered of a compression later on and another compression later on. So, the one compression at some distance x, it would have been actually started, initiated at some t times earlier, right. So, x divided by t is actually c if it had been started x divided by into not. So, x at x distance. So, it would have been initiated some let us say t times earlier and x divided by t is nothing, but c. So, x divided, what we can say is t dash time here we are saying the t dash time are there because t is my general notation for time.

So, therefore, its nature of the wave or quality you know the peak, the amplitude of the particle will be given by y cos omega t minus omega t dash because it started t dash time earlier, not you know lag by. So, it will actually start at t this time earlier. So, the form of the point value of the particle displacement will be simply y t at t equals to at you know current time t yt at current time minus y omega t dash, right and t dash is nothing, but x by you know x by x by t is equals to c. So, I can relate this to c. Let us do that.

(Refer Slide Time: 19:17)

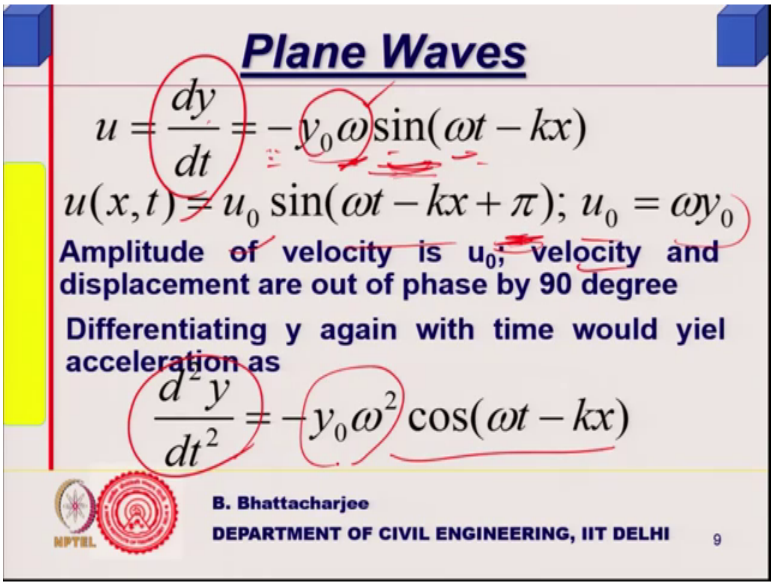


So, y x t particle displacement at any point will be given as y 0 cos omega t minus omega x x by c because you know t dash is nothing, but x divided by c. So, omega I can take it out and if I take omega out or I can write twice by a, both I can write twice pi f. I can write it like this. So, this is written as kf c is equals to lambda f omega is replaced by twice pi f and this is written as k which is nothing, but twice pi by lamda.

So, it is written like this omega t minus kx because it is a function of x and k is twice pi by lambda and is called wave number. It is called wave number twice pi by lambda which is equal to omega by c you know because twice pi by lambda. So, it can be twice pi by lambda and if I write it like this twice pi f c was lambda into f c was both you know twice pi f by twice pi f. So, this is equals to c. This is omega.

So, I can write as omega by c. So, wave number is k. So, the equation particle equation for particle displacement is omega t minus kx. It is just may be you have done some of this our earlier what the repetition is. Since we are looking at noise, some fundamentals are required. So, it is a plane wave traveling, right. It is not spherical wave from plane wave traveling in one direction and that is why x direction only we are taking and this is what it is.

(Refer Slide Time: 20:51)



So, velocity will be what velocity will be derivative of this on dy dt rate of change of because particle moves to its extreme position, come back to its you know zero state or I mean x equals to 0 or y equals to y z you know y 0 and that at starting point and then, again it goes back towards minus y 0. So, y 0 to y 0 and when it goes to the extreme end, the velocity was 0. It starts a quartz certain velocity at the central point and then, because of its inertia a travels further to minus y 0, where the velocity becomes 0 and then, it says to come back and so on because the stiffness of the system it would resist them you know if you were given a kind of displacement, it is the system itself will resist that kind of a displacement. So, it will try to come back to its original state in the process from 0 to velocity becomes somewhere maximum and then, it tends to again go back to 0 and so on and so forth.

So, velocity is a same function of sine functions same as the pressure velocity and pressure. They are both sine function where displacement is cos function. In other words, I can say that velocity and you know there is a velocity and pressure. They both are sinusoidal or varies together and differentiating y equals to y 0 y 0 cos omega t minus x. With time will give me a 1 omega multiplied sine minus sine will come sinusoidal opposing opposite direction as a displacement. If it is moving along this direction, you know the velocity would reduce. Well, it has gone to extremity displacement is maximum velocity is 0. That is what we are just saying, right.

So, u x t is equals to, then I can write it like this, ye.

Student: Velocity displacement.

No if you go back to this, if you go back to this, you know if you go back to this states maximum displacement at t equals to 0, so cos 0 is equals to 1 multiplied by y z. So, this is what it is maximum displacement or y goes to 0. That is why, right. So, anyway coming back to the same thing, so this is u. I can write it like this. U is equals to u xt and u 0.

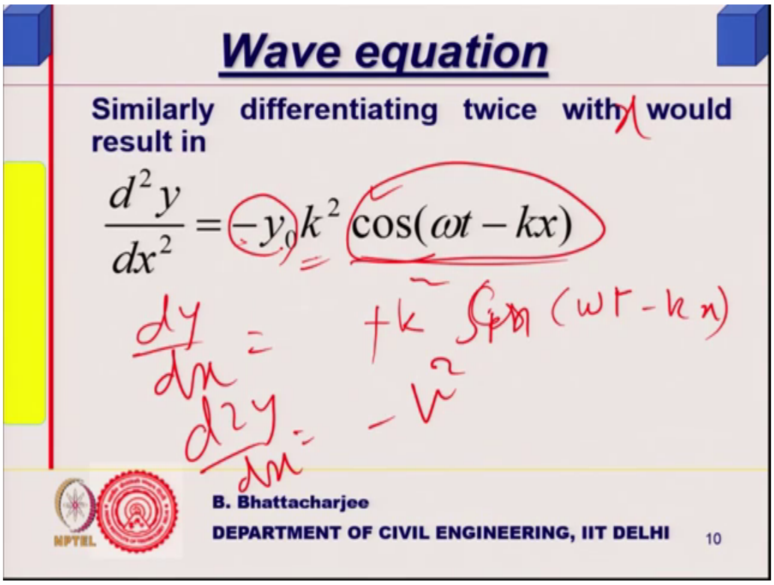
Now, u 0 will be simply minus omega y 0 and sine omega t because it was I can put it as pi, right because sine pi would make it minus. So, omega t minus kx sine remains same. Only this minus sign everyone id written like this. So, u is equals to y 0. You can see that actually this has got a five phase difference, right. Five phase difference with pressure, with a phase difference with you know. So, anyway this is a phase angle. I can put in and I can write u 0 just omega y 0, right ok.

Amplitude of velocity is u 0. So, velocity amplitude is u 0 and displacement are out of phase by 90 degree. So, they are a1 is sine, another is cos 1 is sine, another is cos, right. If I differentiate it again why what will I get? I will get acceleration. So, you know it will actually accelerate. So, this will become this minus sign remains and it will become omega square and it will become cos omega t minus kx again, right.

So, acceleration is given by this, velocity is given by this and amplitude of acceleration will be somewhere there. So, that means what acceleration and displacement is, when acceleration is equals to zero displacement is also equals to 0 and that means, when I have taken it here, it tend to accelerate at a very fast rate from zero velocity to a higher velocity and when it comes back to starting, I mean original point from where I have pulled it, it will actually show acceleration equals to zero velocity at its maximum because it will cut it down. Now, we have to try to reduce it down anyway. So, this we can understand.

So, from this we can get some idea about the wave equation and you know we will try to look into it because there is some relevance of this one. Although we are not solving the wave equation, but if you are interested in it you know in a further conceptual understanding or certain things, later on you have to maybe you have to solve wave equation somewhere. For example, transmission loss through layered wall and so on although we will not use it much, but I derive it to define something called acoustic impedance. So, we need to derive it for the purpose of understanding what is called acoustic impedance. So, if I differentiate, we have differentiated twice got acceleration.

(Refer Slide Time: 26:24)

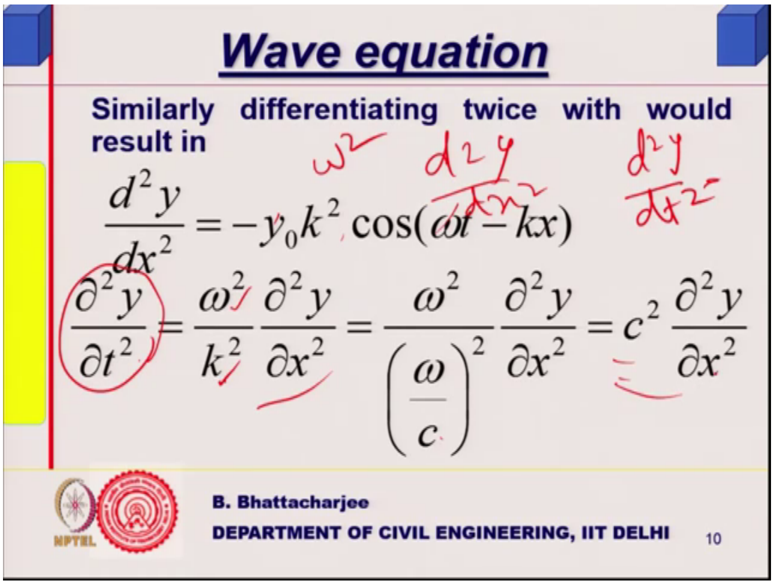


I can differentiate twice with respect to x. What do I get? I have differentiated with time to get the acceleration, but y is a function of x and t. So, therefore I can differentiate twice with x also. So, if I differentiate twice with x that would result in k coming in here. First it was y 0 cos omega t minus kx, right. So, sine would have become minus and there is it would have been plus right, but second time when I differentiate, then will come again back here because originally it was cos omega t minus kx.

If I differentiate with respect to x, I will get minus k sine omega t minus kx. You know du d x would be simply minus k will come, right because I am you know, I am multiplying by minus k and then, when I say minus plus is equal to plus actually because sine cos if you integrate cos what do you get minus sine or sign and then, second time I do it there will be a minus. So, that is how the minus k square comes in k squared cos, right.

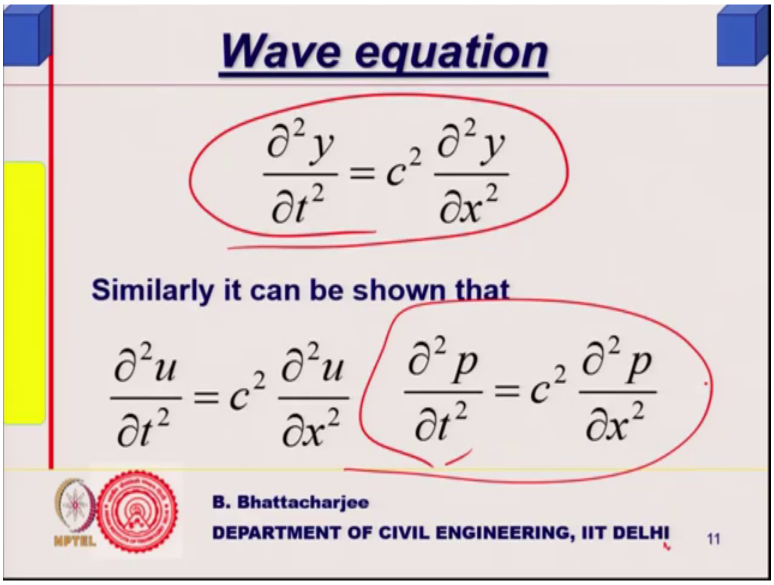
So, you can see this is same in both the cases. So, y 0 this is also same. So, if I take ratio of these two what will I get? If I take ratio of these, two ratio of this two?

(Refer Slide Time: 27:55).



If I take ratio of this two ratio of this 2 d 2 y dx square and ratio of t square y dt square by this. If I take it, this terms will cancel out and I will be left with you know how much what was whatever, this term omega square, right. In case of this one, it was omega square. So, I will be left with omega square by k square and what k is, we defined it as omega by c wave number. So, omega, so this comes out to be you know equals to this, right.

(Refer Slide Time: 28:45)



So, you see this is what it is. This is what the wave equation is. This is what is called wave equation in one dimension. This is what is wave equation, in one dimension, but if I repeat this process for p, I will get same thing p. Only thing it was now starting with sine and if you twice differentiate, sine will again come back and velocity also same thing. So, therefore this twice differentiated time and twice differentiates with x.

So, you know nature of the equation as you can see earlier, we had heat. Did heat transfer? This was you know dtd temperature field variable was my temperature and temperature was simply it was a parabolic equation. This is not parabolic, this is actually wave equation is hyperbolic. This hyper was not elliptic hyperbolic equation. I think is hyperbolic differential pd partial differential equation. So, ask any questions, we will answer and then, will follow from here.