Experimental Physics I
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Lecture – 38
Experimental demonstration on the standing Waves on a String has been shown clearly how to determine the linear mass density of the string

So, today we will discuss about the transverse and longitudinal wave and we will show you how we can measure the velocity of the waves. So, let us know what is transverse wave and longitudinal wave.

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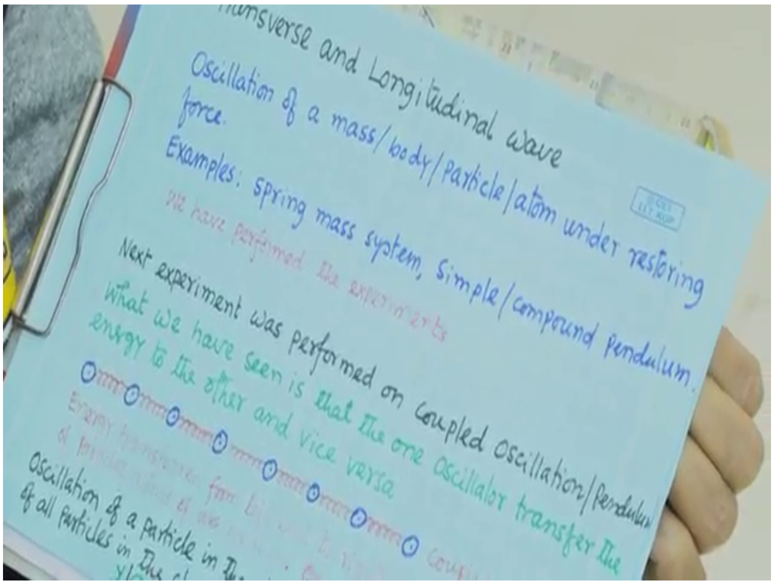

So, oscillation of a mass, body, particle or atom under restoring force right. Oscillation of a mass is nothing, but the oscillation of a body under restoring force.

So, as per example we have seen this spring mass system, simple or compound pendulum. So, these are the standard examples of this oscillator simple harmonic oscillator. So, this is single particle it can be a heavy mass it can be a very light mass like atom. So, they can oscillate if there is a restoring force.

So, we have performed the experiment of spring mass system and compound pendulum there in our earlier classes. So, next also we have performed another experiment that is coupled oscillation or coupled pendulum.

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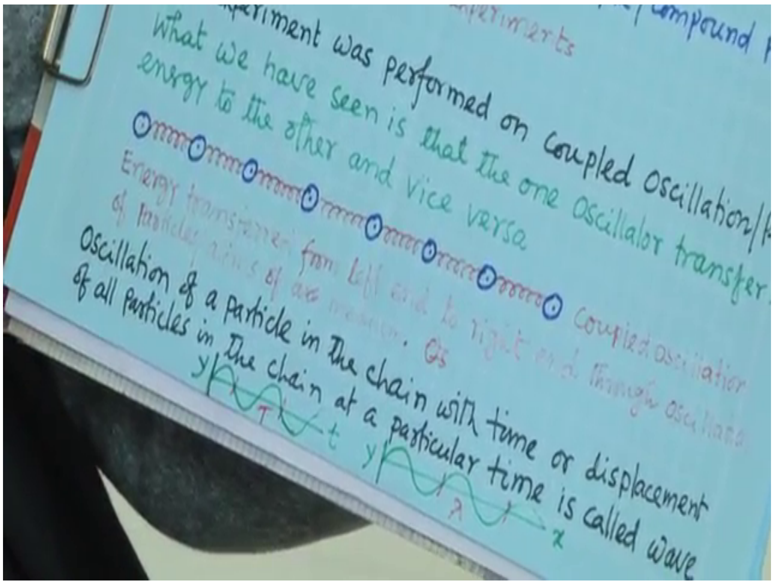

So, basically 2 simple pendulum was coupled with a spring. So, that is a coupled pendulum coupled between 2 pendulum and that experiment we have performed and what we have seen? If I disturb once one oscillator then that disturbance that energy transferred to the another oscillator right. So, now, we think if I coupled many oscillators similar oscillators then if I disturb once then this disturbance the, this energy will transfer to the next one then from next to the this other one. So, that way ultimately what will happen? So, if I disturb this first one the disturbance will reach to the to the end of the basically string of oscillators ok

So, basically coupled oscillator; so, if you can think is this is the mass spring mass system. So, many masses are coupled through the spring. So, this is basically couple oscillator. Now if I just disturb one this first one, so, that disturbance will transfer to the second one from second to third. So, that if you reach to the other end ok

So, something is travelling the energy is travelling. So, these travelling through the oscillation of the medium of the medium so, now, whatever we tell this waves are moving. So, waves are moving through a medium say sound wave it is moving through a through a through a medium. So, basically disturbance at one place is reaching to the other end other places ok. So, that is that is basically due to the due to the oscillation of the atoms of the medium ok.

So, this waves that concept is coming from the bicycle oscillation. So, is the oscillation oh it is nothing, but the collecting oscillations of many oscillators coupled oscillators. So, when we consider a medium. So, we take it as a continuous medium so, but this medium is made up atoms. So, we can take the area of the atom in a medium. So, these your waves is passing through this through this array which is basically it is passing through the oscillation of this array ok.

So, that is the wave. So, waves from oscillator they couple oscillator from this from this couple oscillator oscillation of couple oscillator is basically that waves oh it forms waves ok. So, oscillation of the particle in the chain with time or displacement of all particles in the chain at a particular time is called wave.

So, if I tell over this the picture you know just it will come in your mind that it is just varying like this it is varying like this like. So, these variations what is varying? It is basically its whatever varying we are telling there is a amplitude what the oscillator is varying amplitude of the oscillator is varying as a function of time or as a function of distance or as function of both.

So, basically wave will be then oscillation of a particle in the chain as a function of x or t or both that is a wave. So, this variation here is displacement of a particle in the chain is varying like this with time with time. So, that is a also is away for also this displacement is varying as a functional distance in the chain. So, this variation is also like this. So, this is the wave form this is the basically we are telling wave. So, this wave is.

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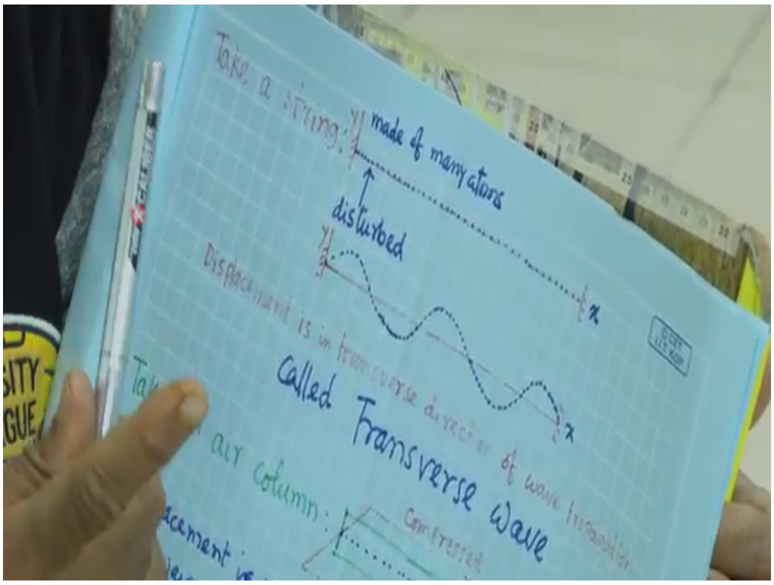

So, basically if you now you take a spring. If you take a spring of wire or a thread and this thing is basically made of many of those it is made of many of those. So, disturbance if you disturb at this place the disturbance will move, then it moves like this ok. So, these we have to tell this is a wave right.

So, wave is nothing, but the see this individual displacement of individual atoms of the chain of the spring at a particular either at a particular time as I told or if at a particular time then you look at the particular position; means, we see the oscillation of a particular atom on the of the stream or at a particular time just if you take picture. So, this, so, at that time what is the position, what is the displacement of all atoms on the spring?

So, this the displacement of all the atoms on the spring will be like this for a particular time ok. So, at different time this form changes this form changes. So, so this is the basically is the concept of wave. So, this when the displacement is in a transverse direction or the perpendicular direction of the motion of the perpendicular direction of the motion of the wave, then that wave is called the transverse wave.

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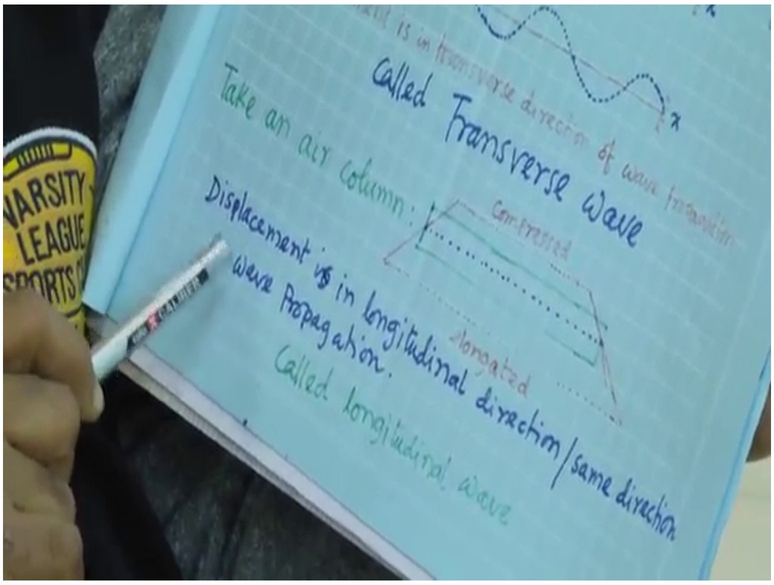

If the displacement is in longitudinal direction or the same direction of the of wave propagation then we tell the longitudinal waves ok. So, here just we have set up for a transverse wave as well as for longitudinal wave.

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So, here you can see this is a string this is a string is the basically thread ok. So, we have taken that distance between this string distance between the string between this end and this other end, we can resend this other end.

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So, this other end basically here we will put some weight. So, that is a tension of this of this wire of this thread basically. So, we can change the tension of the thread changing the mass of this n. So, this is a basically string here I will show you the formation of transverse wave and then we will measure the some velocity of the transverse wave in the string ok.

So, this is one experiment where we will see the transverse wave and another experiment I will show you I will show you this is the air column ok.

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So, here this here this other end the other end of this tube is basically closed because it is in water and this end this top end is basically open it is a air. So, between this water end and this open end, so, this is a air column is there. So, here if I disturb this air column, so, here this is basically longitudinal wave will be on that I cannot show you, but transverse wave I will show you. So, this basically is example of longitudinal wave this other one is example of transverse wave. So, let us discuss about the about the, of working formula for these 2 experiments.

So, you know this super position of the waves ok.

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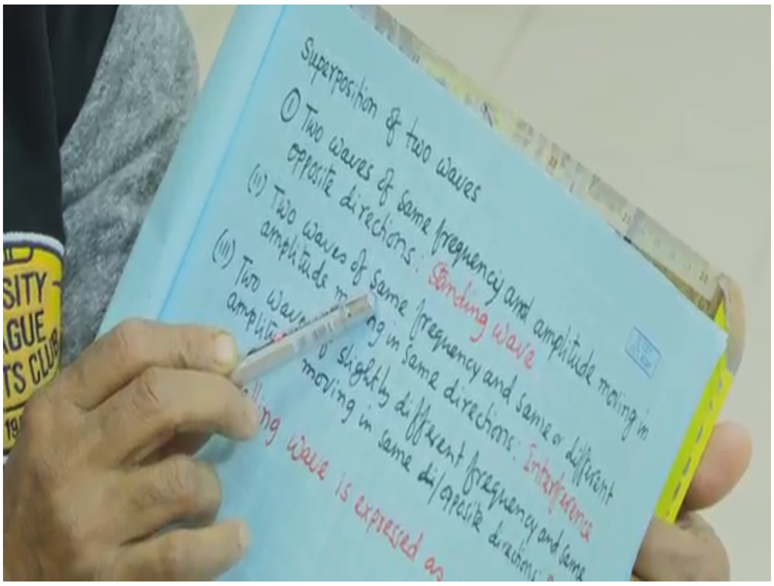

So, here basically super position will work super position of 2 waves; so, 2 waves of same frequency and amplitude moving in opposite direction, ok. So, in this condition we get standing wave. 2 waves of same frequency and same or different amplitude moving in same directions ok so, then we get interference.

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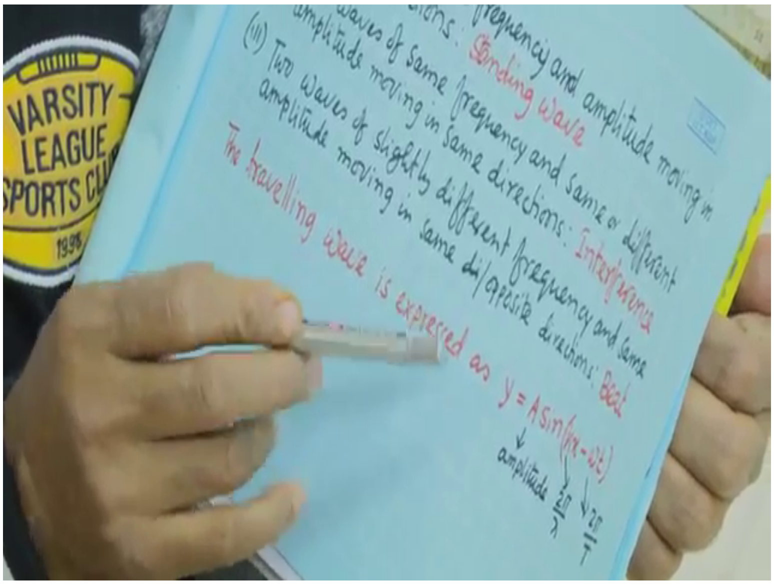

Two waves of slightly different frequency and same amplitude moving in same or opposite direction then it form the then we tell its beat ok. So, this is the superposition of 2 waves. So, here basically whatever you will see that is the basically superposition of 2 waves ok. So, it may be longitudinal or transverse. So, this wave travelling waves expressed as a, this y is a basically displacement equal to a amplitude A sin kx minus omega T. As I told that this wave equation will be wave that is basically here the displacement of oscillator individual oscillator. So, that when that is function of x and t then that is the wave equation basically ok.

So, y equal to A sin tx minus omega t. So, k is 2 pi by lambda is to tell we tell this k is a vector wave vector. So, it is a k equal to 2 pi by lambda and omega is 2 pi by T. So, lambda and T; this is the lambda is the periodicity in length and this T capital T is the periodicity in time ok.

So, that is what I showed you that 2 picture you can take; one is at a particular time that as a function of x. So, then this periodicity basically I have shown in the next page I guess next main ok. So, let me show you here. So, this is the periodicity in length ok. So, here periodicity, so, if you take this then this is the complete period complete one. So, that is the periodicity that is the, this is the length this length is basically lambda ok. So, lambda is the wave length basically and bvt is nothing, but the periodicity in length and if I plot it as a function of time, so, similarly we will get this type of nature of disturbance of displacement ok. So, then this periodicity will be time and that that is what we tell time period.

So, this is the wave equation y equal to A sin omega t A sin kx minus omega t where omega is 2 pi T and k is 2 pi by lambda right.

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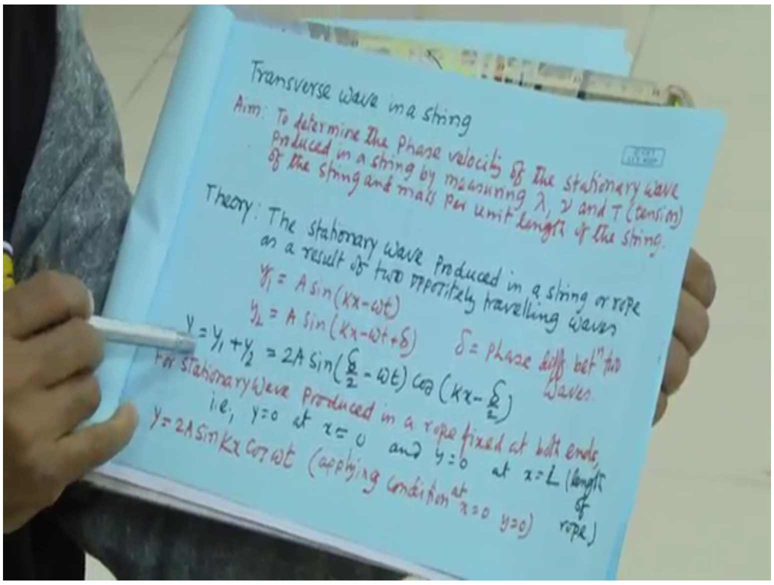

So, so, transverse wave in a string that experiment as I showed you I will show you transverse wave in a string. So, what is the aim of this experiment? Aim of this experiment used to determine the phase velocity of the stationary waves produced in a string. So, to determine this phase velocity we have to measure basically wave length lambda frequency mu frequency mu and time period T ok.

So, of the string and mass per unit length of the string; also from this experiment you can measure the mass for no you have to know this mass per unit of the length. So, if you know if you know this yes if you know the lambda new frequency time period ok, either measuring or some supplied value and here mass per unit length of the string probably this will supply mass per unit length of the string this will be supplied and other you have to measure. So, for travelling, so, transverse wave.

So, basically we will produce stationary wave in the string. Why stationary wave will be produced? So, definition of stationary waves I have told you. So, here I will tell for you that why is the stationary waves we are getting here. So, super stationary wave you will get because of superposition of 2 waves ok.

So, y one equal to A sin kx minus omega t and y 2 equal to A sin kx minus omega t plus delta. So, when stationary wave form? When they when they move in opposite direction as definition I told you stationary waves is same amplitude and same frequency.

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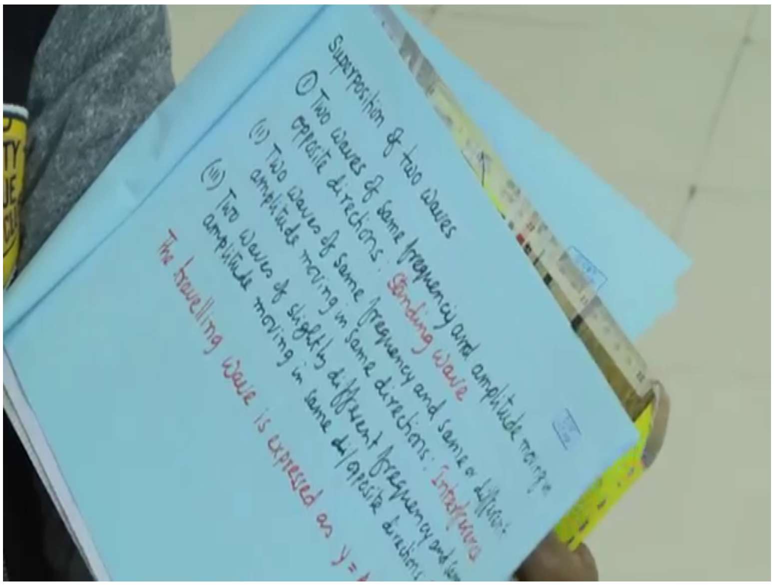

Two waves of same frequency and amplitude moving in opposite direction ok. So, then it is a standing wave. So, here, so, this is the superposition between these 2 waves superposition between these 2 wave ok. So, that y equal to y 1 plus y 2 and from here you can find this relation ok.

So, 2 A sin delta by 2 minus 2 minus omega t cos kx minus delta by 2; so, delta is basically phase difference between the 2 waves so, that can be 0 also, but that in general this is the term of its called phage. So, now, if you put the boundary condition one is y 0 at x equal to 0. So, you know string. So, length is a basically x. So, this x equal to 0 also y equal to 0 at x equal to L.

So, just 2 excision of the string at one end x equal to 0, so, other end x equal to capital L so, displacement at this 2 points is 0 right. So, that is a y it is 0 and using this boundary condition basically this y equal to 0 at x equal to 0, if you use this boundary condition then y is this one right. So, x equal to 0 means kx part will go kx part will go; so, cos delta by 2.

Now, here you are getting 2 A sin kx sin kx omega t. If we use this when we apply condition at x equal to 0 y equal to 0 if you put there, so, then you will get some condition ok. So, putting this condition in this equation you will get ultimately y equal to 2 A sin kx cos omega t and then because some terms will come cos delta by 2 ok. So, from there you will show that delta is basically 0 that was cos detla is 1. So, that is why if you come in this one.

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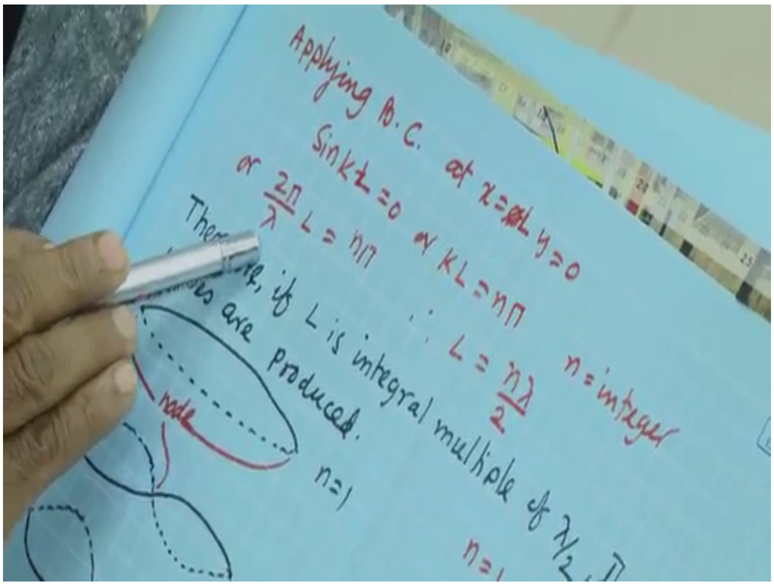

Then another condition if you apply at x equal to capital L y equal to 0. So, sin kL equal to 0. So, from here you are getting kL equal to n pi n is integer. So, k is 2 pi by lambda into L equal to n pi. So, L equal to n lambda by 2 ok, lambda is a as I told wave length wave length. So, that periodicity in space periodicity in length, so, that is the wavelength and n is called mode ok.

So, for n equal to 1 you tell this as a fundamental mode or the first mode. So, when it oscillates, so, it has different mode. It is a fundamental mode then overt tones or we tell first harmonic second harmonics ok; n equal to 1 2 3.

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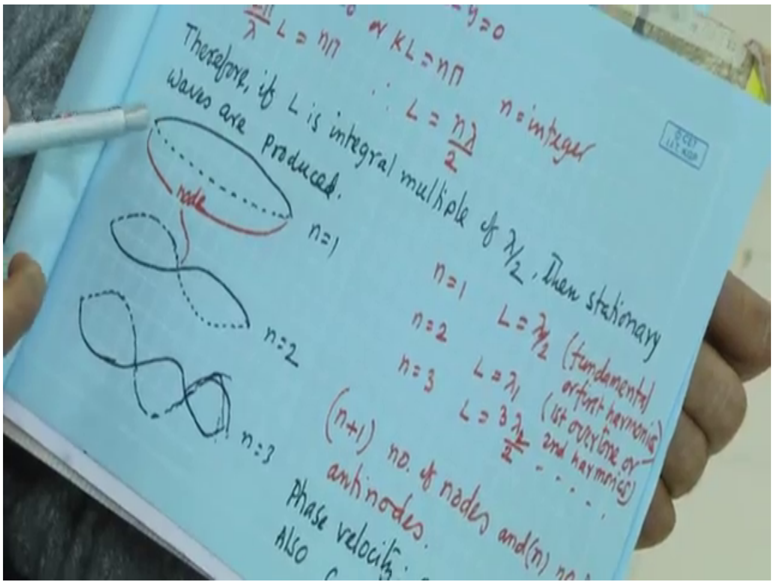

So, first harmonic, second harmonic third harmonic; first harmonic is basically it is called fundamental for that n equal to 1 ok. So, for n equal to 1 then that string you will see in this form ok, the string you will see in this form. So, this is called anti node and this wave y equal to 0 this is called node ok.

So, here n equal to then we tell this n equal to 1, so, there is a fundamental mode. So, that means, if number of anti nodes is 1. So, that is a fundamental node or first harmonic. If this number of anti nodes is 2 in the string, so, then n equal to 2. So, this is the second harmonics of fast forward tone ok. If n equal to 3, so, 3 anti nodes. So, if I can count the number of nodes or number of anti nodes basically we will count number or anti nodes then from here and length of the string I know and I will count number of nodes or anti nodes basically anti nodes n. So, then I can find out lambda. So, I can find out the wave length lambda right. So, if I can find out the wavelength of wavelength lambda then velocity is equal to it is called phase velocity is a 2 types of velocity; one is called field velocity another is called good velocity.

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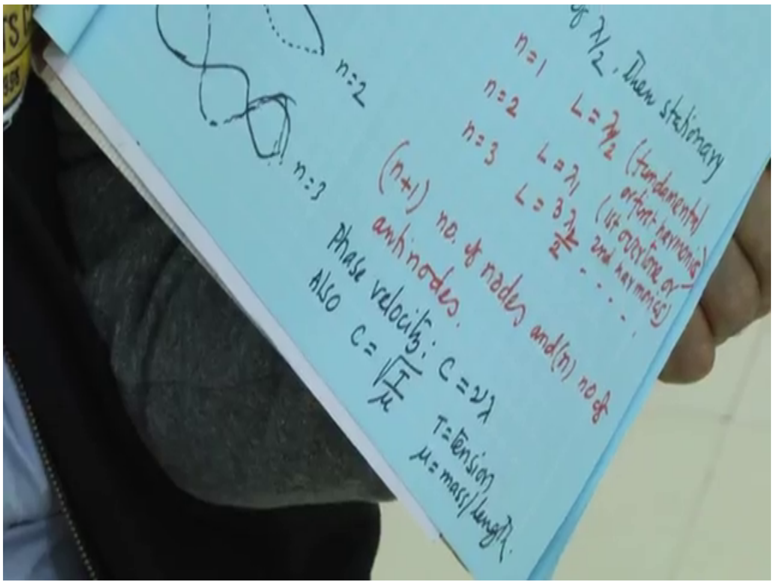

So, I am not going with that for just simply concentrate the velocity of this waves. So, this C equal to mu lambda, so, this is a standard formula right. Velocity equal to C velocity C equal to nu lambda; nu is frequency and lambda is wavelength. So, so nu, nu is frequency. Now in the string, string basically I have to vibrate the string. So, then this stationary wave will form. So, why stationary wave, wave will form that I will tell you. So, I have to, so, vibrate this string. So, that I haveso, this what is the what is the frequency of this vibration whatever we are we are we introduce we will introduce to the string, so, that nu if I know that nu if I know. So, for different nu lambda will be different because C is constant ok.

So, experiment is we will we will apply different frequency and for that we will find out lambda and here we will find out the resonant condition in resonant condition amplitude will be maximum amplitude will be maximum ok. So, then you can see easily ok. So, without resonance also its there will be vibration there will be standing wave, but we cannot see the variation of amplitude because it will be very small but at resonance condition with that amplitude variation will be maximum and easily you can find out the nodes and anti nodes ok.

So, so, basically, so, we will vary the frequency and we will find out the we will find out the number of anti nodes when number of antinodes is 1 then we will tell this is the fundamental mode if number is 2 number of antinodes is 2 then we will tell this is the first over tone etcetera.

So, our experiment is to in the string we will vary the, we will vary the vary the frequency and find out the different modes and for that different modes. We will we will we will get the lambda because this formula as I told you L equal to n lambda by 2; so, so, we can calculate the C. Also C is square root of T by mu. What is the T? T is the tension as I showed you. So, we will put different mass and for that different mass for this different mass this string will be under different tension and if I know the mass of the mass of the string per unit length, so, that is mu. So, square root of T by mu that is the velocity that is the velocity of waves in the string ok.

So, this velocity also we can find out because T is known to us because I am putting mass this T is known to us ok. So, and this if you know the mass per unit length of this string, so, then you can calculate C or so, from this measurement C you are getting C you are getting. Now you can use this C here. So, C is known to you and T is also known to you because you are putting different mass you can find out this T tension ok.

So, that will be basically mg, mg tension mg for mass m. So, from this then you can find out the mass per unit length of your string ok.

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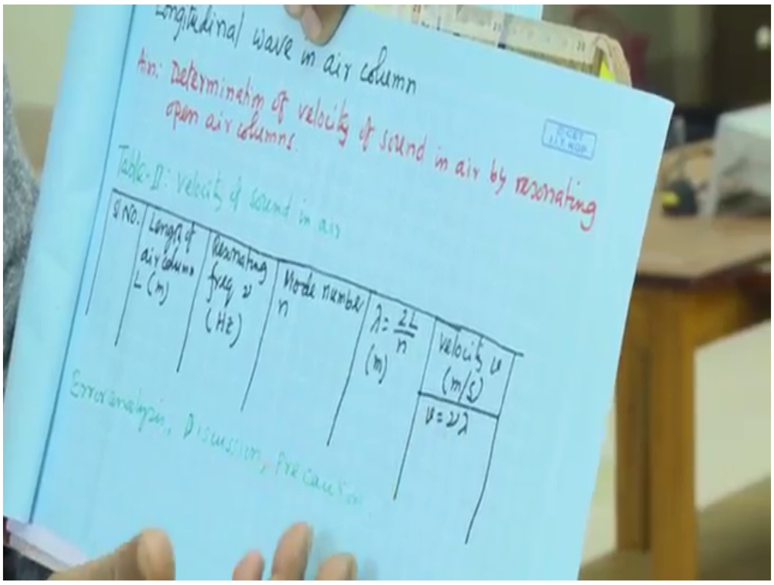

So, this experiment let us yeah I will show you and then second experiment I will show to you this is longitudinal wave in a air column longitudinal wave in a air column. So, for this experiment again, so, basically our aim is to determine the velocity of sound in the air by resonating open air column. So, I showed you guys open air column. So, we will find out the velocity of sound in this through this air column and that method we will use that is basically called resonating open air column ok.

So, I will tell you this for this basically again this formula whatever we got L length of the string or length of the air column L equal to L equal to L lambda by 2 that is that is what I think we got, L equal to L lambda by 2 ok. So, again this n is I think yes it is mode is the mode. So, n equal to 1 this fundamental mode or fundamental this waves and then over tone and then first or first harmonic second harmonic.

So, n equal to 1 2 3 etcetera that is a I already I had described to you. So, this is hot stationary wave. So, in air column also stationary wave will be formed and this whole formula is will be used. So, in that case also I have to find out basically n. So, that n we will find out of I think or lambda we will find out.

So, this for a particular resonating frequency we have to find out this length of the air column. So, L we know L we will know. So, this length whether it is for first wave first the, for fundamental mode or over tones that we have to we have to find out. We have to find out varying the length of the air column varying the length of the air column ok.

So, basically here mainly we will use this we will use the fundamental mode for different frequency. So, for different frequency resonating frequency we will find out fundamental mode and for each case we will see this length will be different; that means, lambda will be different ok. So, we find out the lambda and then C equal to again lambda, a new lambda. So, resonating frequency I know n lambda we will find out. So, velocity of sound will be C equal to new lambda ok. So, again here we have to measure the lambda find out the ma lambda. So, lambda we will get from this measuring the resonating length of the air column ok.

So, let us just quickly show you experiment this is very simple experiment let me show you this first transverse wave ok.

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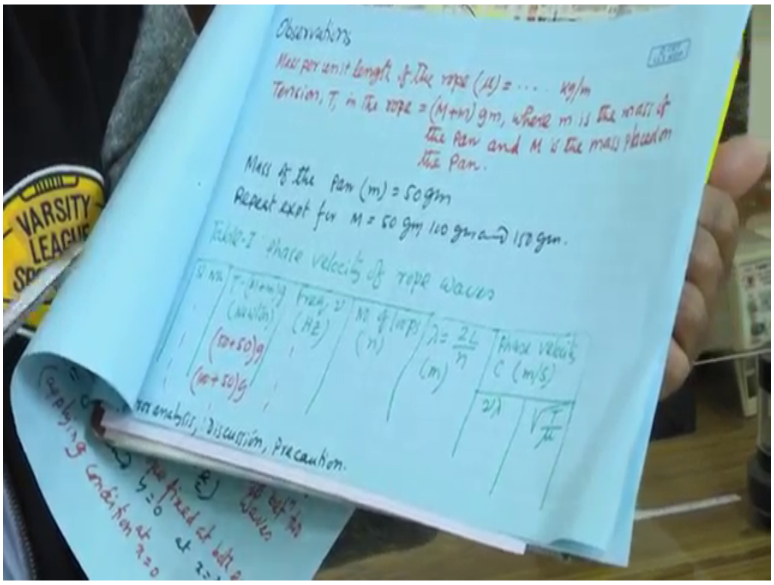

So, observation what we have to do? First we have to we have to mass per unit length of the rope. If it is known that you have to note down and then tension T in the rope tension T in the rope. So, tension T in this rope here you see this there is a pan here on top of pan we are putting mass. So, this weight of this pen is 50 gram. So, this capital L capital L that is basically the small m is the mass of the pan and capital m is the mass placed on the pan ok. So, small m is basically in our case this is the mass of this pan it is 50 gram and now we have placed at right now we have placed this 50 gram. So, that is capital m is 50 gram. So, these are totally 100gram ok.

So, tension T is basically mg. So, 100 gram and this g of acceleration due to gravity that value is known to us. So, that you have to note down mass of the pan is 50 gram and we will repeat the experiment first we have put 50 gram then we will put 100 gram then we will put 150 gram. So, for T tension for T tension means for 3 mass of capital M we will repeat the experiment. So, for a single mass let me just show you and same way you can repeat the experiment ok.

So, for the table serial number and then what is the mass? T equal to capital M plus small m this in gram sorry g. So, this tension is in Newton. So, mg basically as I told ok. So, that you have to so, for each tension we will we will take reading of this frequency. What is frequency? So, that I will show you now. So, frequency here you see I had a string. So, now, the string is under a space under a under a tension ok, it is under its tension.

Now here, so that end of the string is under tension and this end of the string here you see now I have to oscillate the string you know. So, so with some frequency ok. So, I have to vibrate this string with some frequency. So, here manually I will not vibrate the string, here we are using 1 vibrator electrical vibrator ok.

So, you can see it is the its just vibrating. So, basically instead of I am not using my hand, basically we are using vibrator to vibrate this vibrate this string. So, now, the frequency of this of vibration I can change. So, I have a meter, frequency meter ok.

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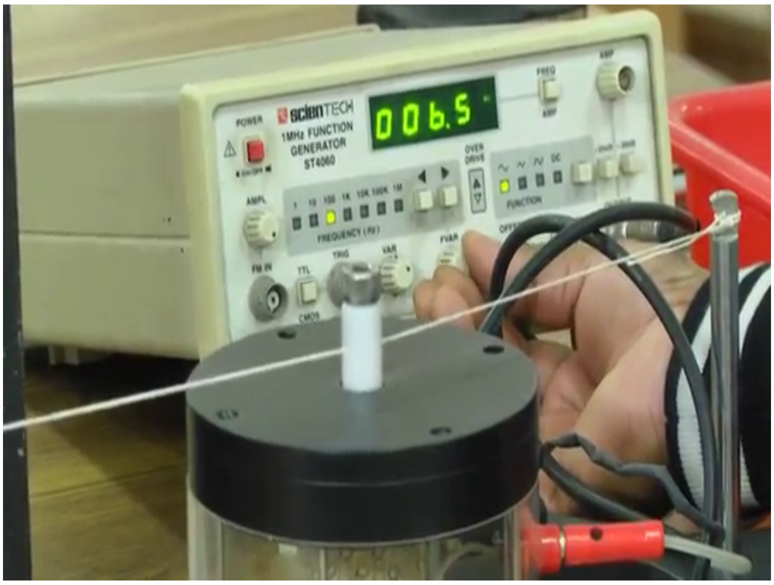

I can change the amplitude as well as the frequency of this vibration. So, if I change the if I change the frequency if I change the frequency you see now there will be some resonant condition you see. Let me show you for smallest frequency for smallest frequency is no. So, I have to change vary yes.

So, looks it is you see yes it is very sensitive to the frequency ok. So, ok, so, here you can see. So, you are getting a 1 node, a 1 anti node in this vibration ok. So, n equal to 1. So, length of this wire is of this string is we have to measure. So, it is a, that we have to measure we have we have meter scale we have basically meter scale.

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So, one has to measure it. I am not going to measure, but we have to measure the note down this length of the string for this. So, L is known to you L is known to you. So, that L we have to I think that L we have to note down ok, this L we have to note down. So, lambda equal to 2 L by n. So, now, for this case L is known to you. I think we should write on top of it because this capital L is on the time for this experiment is fixed.

So, now, here n is number of root for this case is the 1 and for this at which frequency I got, so, that frequency I have to note down so, 8 it is a varying from it is a varying from 8.7 to 8.9.3. So, I will take it as a 8.9. So, basically, so, then you take basically for each case you just take 3 readings and then average of this 3 frequency you take the frequency of this for this standing wave for this fundamental mode. So, there is you have to note down. So, then again I will change the frequency for higher mode higher harmonics ok.

So, let me vary and find out this n for this second harmonics. So, it is a it almost double it almost double ok, yes I have to be very careful, now slowly I have to change yes done, you see. Now, this 2 number of antinodes is 2 ok, number of antinodes is 2. So, this is for 24 hertz, also you have to note down the this least count of this frequency meter and that is basically 0.1 hertz ok. So, you have to note down this frequency and for that frequency number of for that frequency number of loops you have to note down. Now number of loops 2, now then we will change frequency. Number of loops you will get 3 ok.

So, this way you have to just for a particular tension T. So, at least you take 3 reading 3 for 3 n. So, number of loops is say 1 then 2 then 3 corresponding frequency we have to note down and then we calculate lambda and if you calculate lambda mu is this. So, you will get the phase velocity C right and also you will get from this square root of T by m T is known to you and mu is if it is given. So, then we use and then find out this C and then we can compare or I will use this C for this calculation and I can calculate mass per unit length of the string, so, from this experiment also ok.

So, then another analysis discussion precaution that is the standard steps we have to do since I have discussed these things in many for many experiments. So, this same thing I will not discuss here.

So, next just if I go for the longitudinal wave in a air column, so, this also as I mentioned. What we have to do? So, basically we will measure the phase velocity of phase velocity in air. So, that is basically sound wave ok. So, basically velocity of sound in air will measure. So, here also I have to find out there here, resonating we have to we will we have to find out the length of the air column. So, this is the resonating length of the air column, so, for a particular frequency. So, we vary this frequency and here in our case we will vary frequency for different frequency we will find out the different length of the air column, resonating when there will be resonance. So, we will we will see.

So, that how we will detect this resonance that is basically hearing the sound we will we will we can identify the resonance condition and then mode number n, n in our experiment n is we will take all the time is 1. So, then we can calculate the lambda. So, n equal to 1 as I told. So, what I have to do only I have to find out the frequency mu for that frequency what is the resonating length of the air column ok.

So, at least we will use 4 to 5 different frequency and for that different frequency what are the different length and then different wave length I will get lambda and for so, then for each frequency we will get wavelength and we can calculate the velocity that we will take the average velocity of this all 5 data ok.

So, after that error analyzing discussion precautions there is a standard things we have to do it. So, let me show you now how we will find out the resonating length of the air column for different frequency ok.

So, here we have this set of ok, so, here see basically , so, we have a water in this what is called in this tube and another tube we have this both end is open and it has scale you know it has scale. So, now, this is a basically air inside this tube is now basically this both end is both end are open ok. Now, if I put in this water in this water. So, now, this end is closed, now, other end is open. Now this air column is this; so, air column I can this length of this air column I can vary right. So, this is the advantage this is the technique we have used that air column I can vary length of the air column I can vary.

So, now I have to find out the resonating length of the air column for a particular frequency. So, now, to vary the frequency I have this tuning fork.

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I have this tuning fork of different frequency this frequency is written here it is 512 ok, frequency is 512. So, this 1 is 300. How much is this? 300 I think, something I cannot read it, but here I can see this is 320, this 320.

So, I have this fork this 300 I think this is 288; so, 288. So, I have here 5 fork this tuning fork and this it has so, it has different frequency, it has different frequency. So, for this five frequencies I find out the resonating length of the air column that is what the experiment then I can calculate the velocity of some. So, 5 velocity I will get and then I will take the average of this ok.

So, let me take just 1 ok, let me take 1 fork let me take this one. So, now, so, just I think; so, I have to vibrate this one then it will emit it will emit wave of that frequency of that frequency whatever written. Now that, so, now, I will keep this resonator close to this air column so; that means, this disturbance will transmit to this air column, so; that means, I am disturbing this air column at this end with this frequency ok.

Now, I will change the length of this air column. So, it has natural frequency no and then when this these 2 frequency will match then there will be resonance and we will hear higher sound in resonance this is basically amplitude will be maximum and square of amplitude is the basically is the basically intensity. So, that is the intensity of sound ok.

So, let me see it ok. So, I am disturbing air column. Now changing the length, now yes, now this is the position for maximum sound yes. So, then I have to take this reading here ok. So, one has to do carefully ok, one has to do carefully yes. Why it is probably, I am touching this one yes ok. So, it looks to be 23. So, this reading is 23 here it is 0. So, this length of air column is 23 for and I have to note down this frequency ok, it is a 320. So, frequency is 320 and this air column length is 23 ok.

So, then the same experiment I have to do for other one, it is the 384 it seems; 384 yes. So, this is the position for maximum sound. So, I have to take reading it is the around 22 ok. So, that was 320 and this was 3 384. So, it is closed value. So, that is why this length also closed, but if I take this very different one; its also 288, this is 341 ok, this is a 512.

So, I should get length lower length at least half of it around 12 by should ok, probably yes. So, I have to note down this one, it is the around 15 it seems, yes around 16. So, this length of this air column is 16 centimeter for this frequency; this frequency is 512 ok. So, for different 5 frequency I will find out the resonating air a resonating air column length. So, this is the experiment then you will get the lambda from L equal to the what is the formula for L equal to 2 L by n L equal to 2 L by n L equal to 2 L by n; n is 1. I am just holding this is the fundamental one; n equals 1 all the time because other also you can find out then you have to take this length should be this higher length.

So, that is why we are not varying this n, we are varying the this frequency and for each frequency actually you have to find out 3 times this air column length and then take the average of it because it is the as you as I showed you this measurement is not determination of this length is where it is not very precise. So, it is varies. So, it depends on the condition of your hearing the sound. So, its better you should take 3 times reading and then take average of it ok.

And then this lambda this frequency is written on this tuning fork. So, that you have to note down and then you can calculate velocity of sound equal to mu that frequency mu into this lambda from here ok. So, this is the very simple experiment, but this is the classic example of transverse event longitudinal wave and wave form also I was able to show you transverse in a string, but this in air column I cannot be cannot see, but you can realize that the same formula we are using for calculating the velocity of sound also. So, similar wave is formed in this air column this node and anti node will be seen.

So, that is why I showed these 2 experiment together so that you can have feelings that whatever in string we saw the standing waves, the same standing wave we this is formed in the air column also that is the basically longed for longitudinal wave.

So, thank you for your attention. I will stop here.