Energy Efficiency, Acoustics & Daylighting in building
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Lecture – 38
Sound within Enclosure (contd.)

So, continuing with the same so, for a room of volume V, total reverberant field energy will be epsilon into capital V for the whole room.

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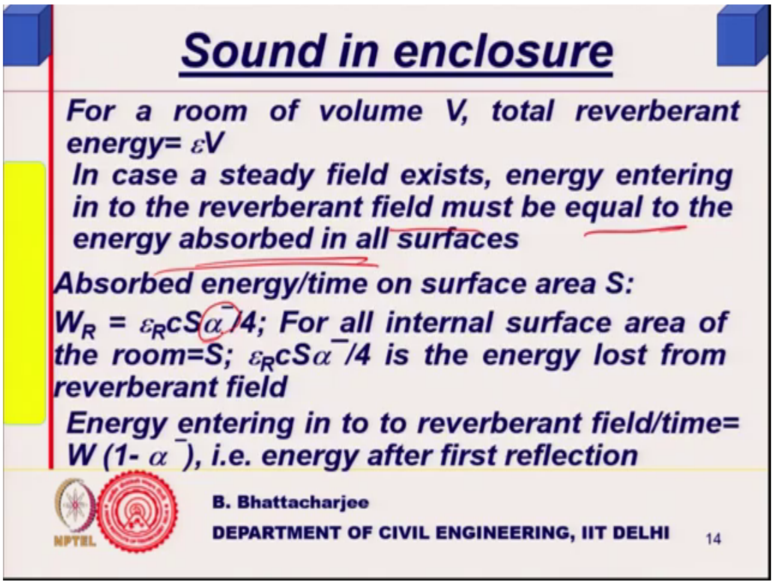

So, now we can apply the conservation of energy for the whole room. So, what is the energy that would be actually entering into the reverberant field is epsilon V right, now and after first reflection after first. So, we got to define something right.

So, energy entering into the reverberant field must be equals to the energy absorbed in all surfaces because how will be the energy enters into the reverberant field after first reflection, because till the first reflection it is all direct sound, till the first reflection it is all direct sound right, after the first reflection is entering into the reverberant field because reverberant field consists of all sound after first, second, third infinite reflections.

So, after first reflection it enters the reverberant field and where does it go if it was not lost somewhere the diffused field would have gone on increasing all the time, but that does not happen. So, there must be somewhere it must be getting lost that is actually get lost at the surfaces of the bounding surfaces of the enclosure through absorption. So, that is what we are saying.

So, energy absorbed in all surfaces, how much energy is incident upon the surface that I have found an expression, how much will we absorbed I must find out now or defining some manner. So, we define a term called absorption coefficient I will come back to this expression later on perhaps I have got an expression for energy absorption.

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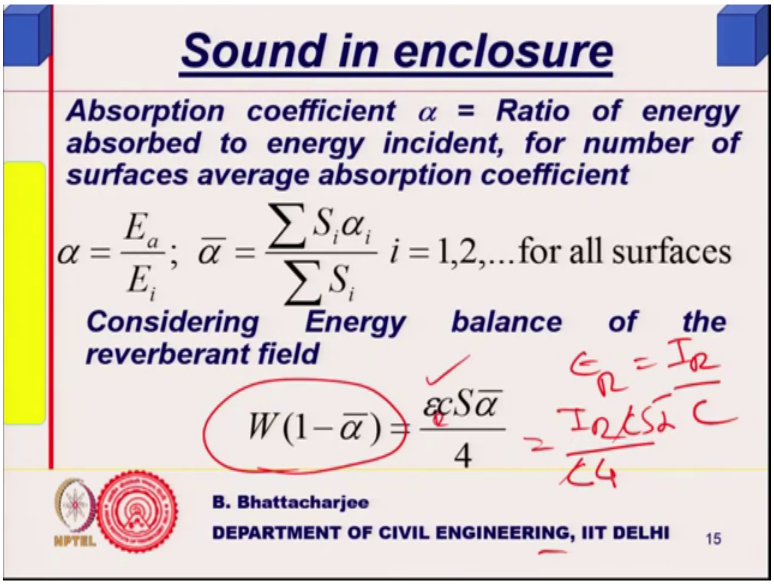

Absorption coefficient is denoted by alpha is the ratio of energy absorbed to energy incident for number of surfaces average absorption coefficient we find out weighted average area weighted average.

So, how much is absorption coefficient of an window and at the incident energy absorbed divided by and at the incident is equals to one open window it will be 1 because everything will go away right. So, energy absorption is defined in this manner here right in the context of sound in enclosure unlike the absorptivity when we talked of heat right we are talking of opaque surface.

So, it will have team 3 component alpha plus t plus R fraction of energy absorbed fraction of energy transmitted, fractional energy reflected right, here since we are interested in an enclosure, how much energy is coming back or how much is getting absorbed?

So, we are defining it in a slightly different manner right for those material for the wall or ceiling material, but if we look at transmission then this 3 issues also comes into picture we will see that later on something ok. So, at the moment ratio of energy absorbed to energy incident for it is a any wall or any surface I call it absorption coefficient. If there are a large number of surfaces because in I do in to in an enclosure I left at least 4 plus 2, 6 surfaces and their areas 2 of them might be same, another 2 might be same, another 2 might be same, but it is not necessarily all are same and their absorption may be different.

For example ceiling and floor absorptions could be different walls may have a different absorption. So, in that case we talk in terms of average absorption coefficient which is defined like this alpha bar. So, alpha is equals to energy absorbed divided by energy incident and alpha bar is surface area multiplied by alpha I divided by sigma. So, this as average absorption; that means, nothing, but weighted average surface area weighted average right multiplied by corresponding alpha.

So, i 1, 2, 3, 4 all surfaces, alpha bar is average absorption coefficient, alpha bar is average absorption coefficient right. So, alpha bar is average so. So, now, then let us let me go back to the previous slide again alpha bar I am calling as average absorption coefficient right and you know average absorption coefficient. So, if you recollect what we said was, energy density into you know energy density into remember we talked of the energy which is incident upon, you know into the volume into what was it is, energy incident let us go back and recollect.

So, this is energy density of the reverberant field multiplied by c divided into S divided by 4 that is what you know. So, let me just go back still further to recover remember.

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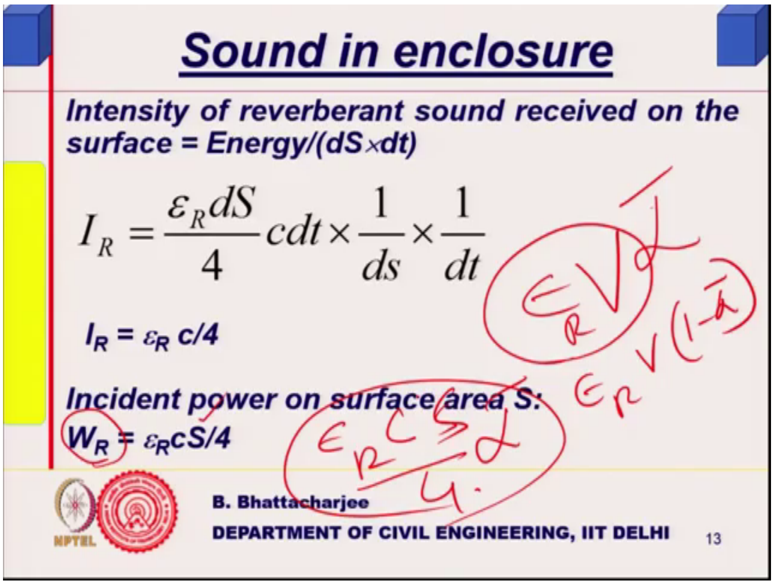

So, this is the power received on a surface S. So, epsilon R is the energy density of the reverberant field C S by 4 is a energy received on to S surface area supposing this S is the whole room surface area then this is energy received on all surface area, how much of it will be absorbed multiplied by alpha bar that will be the energy absorbed in unit time, that is the energy absorbed in unit time right am I right is the incident power because we are talking of power.

So, this is the energy absorbed in unit time in all the surfaces alpha bar I am defining for all the surfaces. So, S is S alpha bar that is what it is. So, this is the energy absorbed in all the surfaces, now this is how the sound is lost from the reverberant field from all surfaces? So, how much is coming into the reverberant field? Epsilon V total V volume of the room is V and we are calling it epsilon R you know which is reverberant field has got a uniform density right.

Now, only after first reflection the energy is entering the grain field. So, in the energy lost in first after first reflection will be this into alpha bar because this is energy total energy contained in the room multiplied by alpha bar is what will be lost in reflection, you know so, epsilon R V into 1 minus alpha bar that is the energy entering into the.

Student: Reverberant field.

Reverberant with and that I might equate to this that I might equal to because energy absorbed must be equals to energy entering into the field and at the entering into the field is of if the volume of the room is V epsilon R into V because his uniform through our into volume that, that is the total energy 1 minus alpha bar is the energy entering after first reflection and that must be absorbed in all the surfaces. So, I can get an expression equating this to which I am doing later on.

So, I have defined. So, you see epsilon V in case of steady field exist energy entering into the reverberant field must be equals to the energy absorbed in all surfaces. Absorbed energy per unit time on the surface S is given by alpha bar epsilon R c S alpha bar by 4 for all internal surface area of the room S, this is in terms of S alpha bar by 4 is the energy lost from reverberant field you know that is what just is mentioned.

So, energy lost from the reverberant field will be given by this and that must be equals to energy entering into the field. So, energy entering into the field is reverberant field is sorry I made a mistake this is not epsilon V, this will not be epsilon V, epsilon V will into 1 minus alpha would be at any point of time, but actual power comes from the W source after first reflection I am talking of W is the power of the source, W is the power of the source because I said I have a steady source.

So, W into 1 minus alpha bar is the energy entering into the field after first reflection not epsilon V, epsilon V will be at any time which would be a function of time we will look into that later on. So, that way we see that this is how we define absorption. So, energy balance therefore, one can write energy balance therefore, one can write is W into 1 minus alpha bar is goes to this energy balance from the conservation of energy one can write this.

Now, this gives me an idea actually to find out I R or reverberant field intensity and then decibel level because E was epsilon density was related to I R remember this is epsilon R and epsilon R was simply I R divided by right I R divided by c, that is what we talked about. So, this is I put it therefore, I can put here I R by c. So, it will be simply I R by c 4 c S alpha bar. So, the c will cancel out, I will be left with I R S alpha bar by W right this is what I think is done in the next slide.

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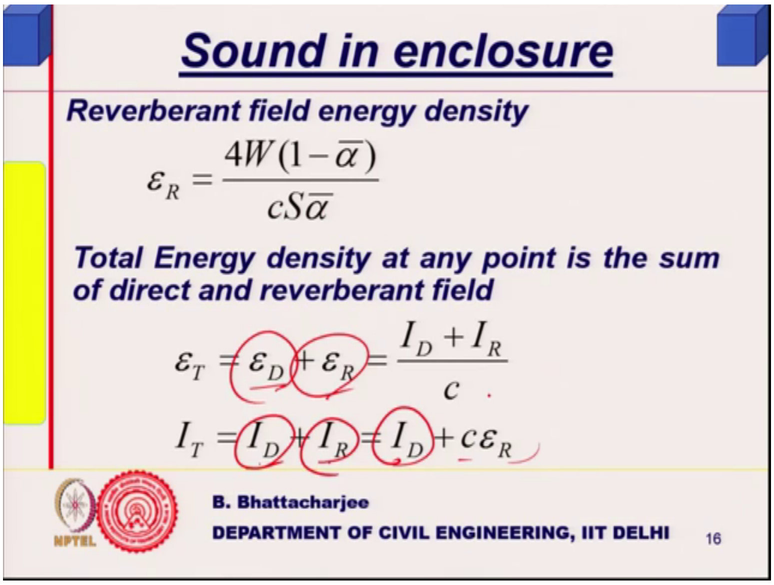

So, epsilon R is equals to you know I get an expression for epsilon R by simply doing an little bit of algebra out of this epsilon R is equals to W this for W into this divided by c S alpha bar that is what has been written c S alpha bar and this I am writing as I R by c this I am writing as I R by c.

So, this is nothing, but I R by c and total energy density will be written as direct as well as reverberant field and intensity of direct and intensity of reverberant field and this is I D is a direct and I R was c into epsilon R and I am just putting it epsilon R here. So, I will get the expression for total 1.

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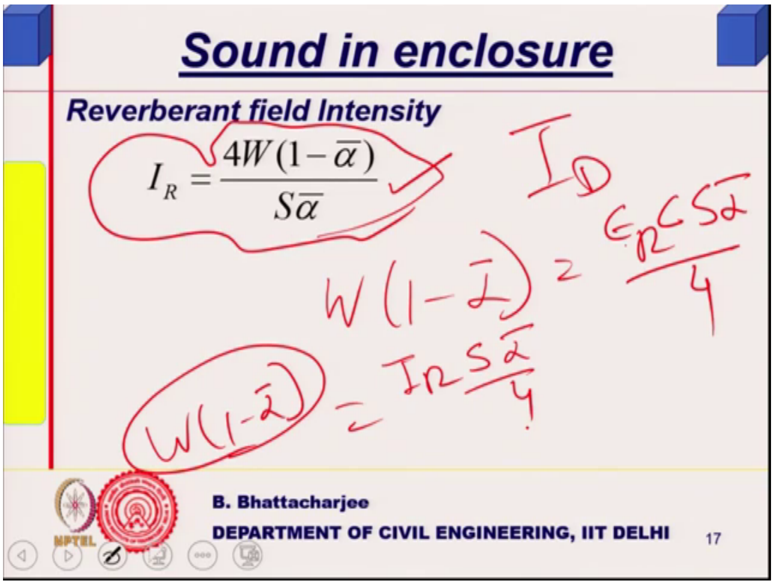

Like this I R is equals to W because c will cancel out you know that is what I was saying W into 1 minus alpha bar was equals to epsilon R c S alpha bar by 4 was it is it right that is what I did right, just what the equation was? Now if I replace this I you know epsilon by I R by c then I get W by1 alpha bar must be equals to I R c cancel out S alpha bar divided by 4.

So, this becomes I R is equals to 4 into W into 1 minus alpha bar divided by S alpha bar right S alpha ok. So, that is that reverberant field density total field density will be given by this plus the direct field at any point, at any point if I am interested I will find direct which is a function of the distance R you know and this is independent of the distance because it is uniform throughout the room.

So, total would be given by this sum total will be given by this sum epsilon density epsilon I D I R. So, this is how it is. So, total will be direct as well as this. So, we will come to that in a moment , now out of all this if you look at it out of all this if you look at it this is the property of the walls this is area of the wall. So, this component is actually property of that you know room property of the enclosure wall properties and the surface.

So, we call a term called room constant whereas, this is the source steady source that I have.

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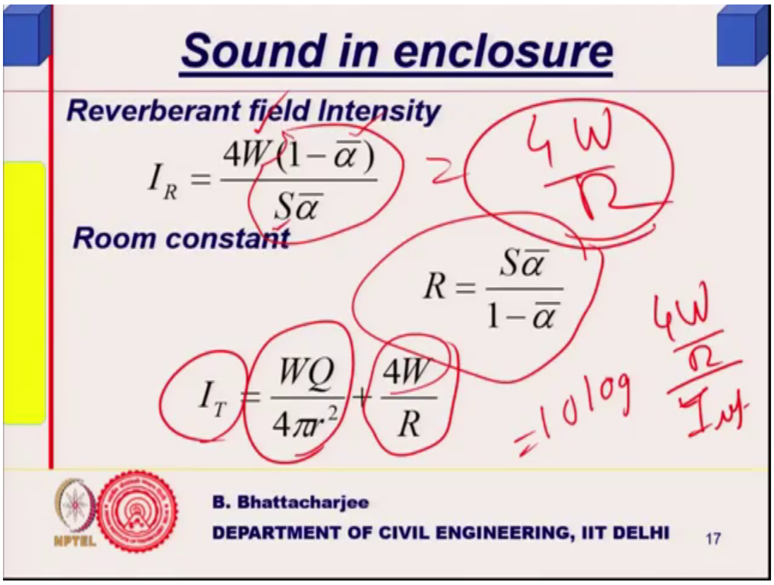

So, I call something called room constant and room constant is defined like this S alpha divided by 1 minus alpha bar, more the room constant less will be the reverberant field intensity less will be the reverberant field intensity right. So, that is right. So, I t therefore, can be written as 4 W by R because this I will replace S 4 W by R and I t was what total was I direct plus reverberant direct is W Q by 4 pi R square remember that earlier we talked of direct field.

So, total I t will be given by this and if I want to find out the total level then I can now divide by I reference and take can lower log of that and that will give you the decibel level due to direct and diffuse field together. If it is only diffuse field then simply take 10 log 4 W by R divided by I ref that will be simply level due to the reverberant field because this is the intensity this divide divided by reference intensity, but then in a room it will be total together any point you will have total only you can neglect one or the other.

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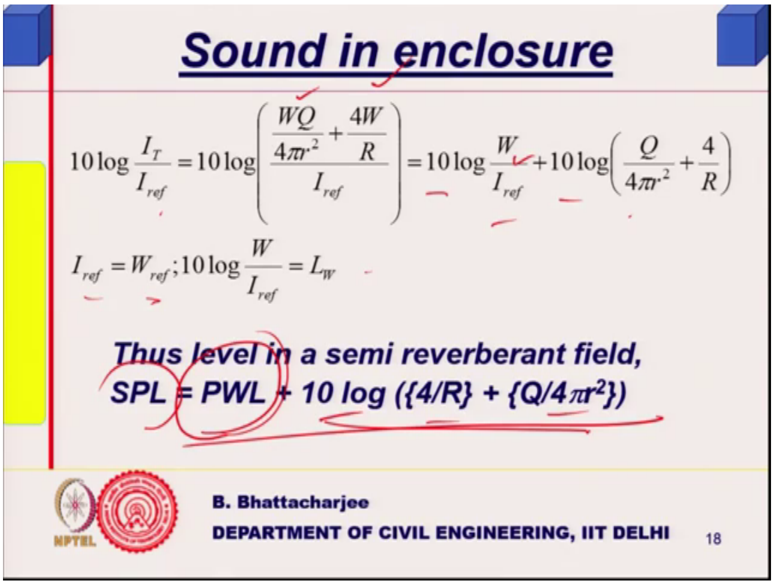

So, therefore, I log I t by I reference is given by this and which I can separate out W is there in both of them. So, I can take out 10 log W by I ref plus 10 log Q by 4 pi r square plus 4 R and I ref we know is equals to W ref and therefore, this is nothing, but L w. So, finally, this is my equation S P L you know because we said the intensity and power level is more or less same assuming rho c is similar rho c is standard rho c and rho c actual not very different.

So, this is equal to power level plus 10 log 4 by this expression. So, these rooms are called semi reverberant room because you have some portion direct as well as some reverberant field existing there. So, we call it semi reverberant field power level plus this right. So, this is what it is. So, I will follow it up, but let me go to the diagram that I had I will go to the same diagram I will go back to the same diagram that I had remember this diagram.

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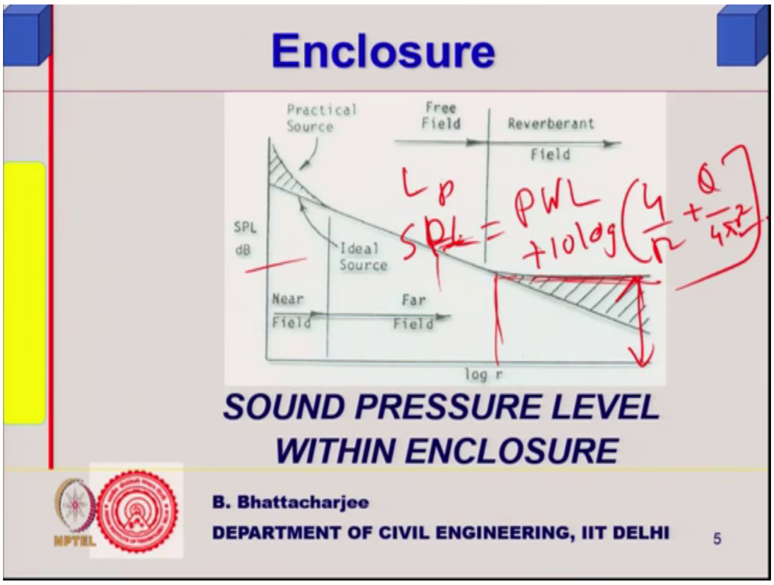

So, level I want to find out any point it will be of direct as well as reverberant field and this will be given as P W L plus 10 log 4 by R plus Q by 4 pi r square. So, this is the you know level at any point level S P L you call it or L I you know L P whatever you call it fall level. So, it is given by this. So, at any point I can find out this, now you look at this at this point at this point you know somewhere around this point direct sound tend to be lower than the reverberant sound right because it is inversely proportional to r.

So, there is a point where my direct field or direct intensity and reverberant field intensity are same that we call as room radius. So, room radius is that points where I have got you know room radius is that point where I have direct field and reverberant field are same directly direct field and reverberant field are same right. So, this is how I am defining let us come to that. So, this is how I am defining right so, room radius.

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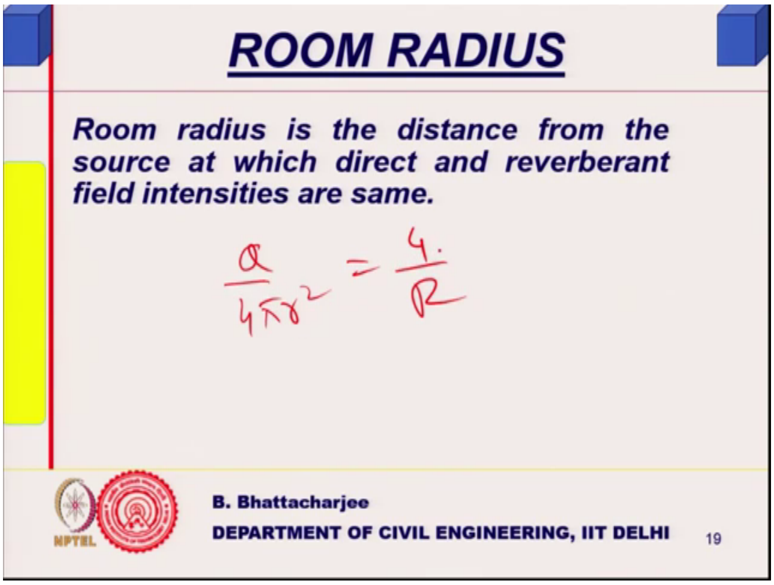

Room radius is the distance from the source at which direct and reverberant field intensities are same and when they can be same Q by 4 pi r square must be equals to 4 by R because W Q by 4 pi r square was because no.

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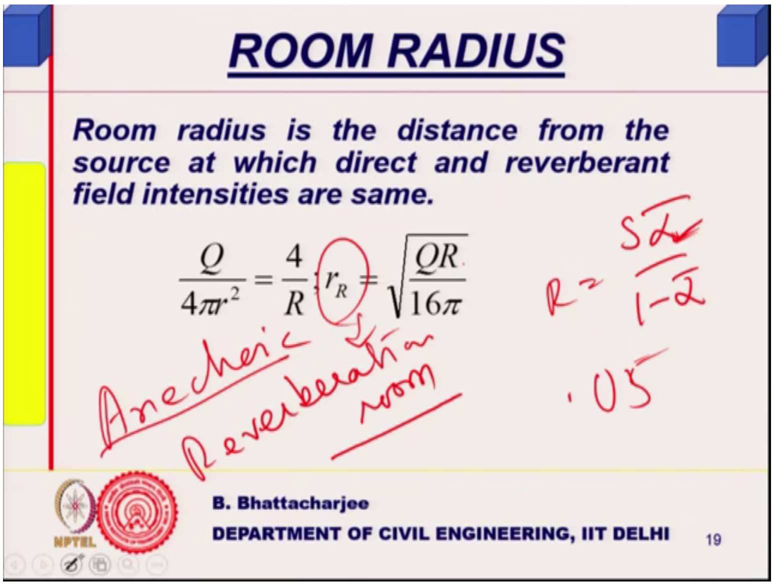

So, you know it would be something like this it is simply written like this Q by 4 by R. So, room radius is given by Q R divided by 16 pi right. Now, if your R is large means lot of absorption because R is what S alpha bar by 1 minus alpha bar. So, for large value of

R this value will be I mean depending our sorry depending on for a higher value of alpha bar for alpha bar can vary from 0 to 1 only.

So, for higher value of alpha bar R value will be you know room constant is it is it will absorb large quantity it will absorb high right because this will be smaller and this will be larger let us say it is 0. 9. So, this 0.1. So, it is high which means that your room radius is for higher absorption room radius is higher and when absorption is very small let us say 0.05 or something like that reverberant field will be more and R is very small.

So, now normal rooms enclosure like these classrooms etcetera they are semi reverberant field, you have some direct sound and some reverberant sound reflected sound some reverberant sound right. A perfect reverberation room where testing is done will have very little absorption values alpha bar will be very small alpha bar will be very small.

So, that most of it is R small R this is small then this is small most of the room is then you get diffused field reverberant field you know you want to do experiments is down on reverberant field reverberation room this is semi reverberant these are called semi reverberant you know semi reverberant or semi reverberation room sort of semi reverberant field you will have both direct as well as reverberant in most of the classrooms auditorium.

But there are rooms where experiments are conducted you want to find out the absorption coefficient this done in reverberant room. If you want to find out the characteristics of a machine is directivity then you do it in an anechoic chamber, anechoic chamber is where you will have all direct sound, absorption will be very little because you have to isolate the room from surrounding no noise should come from anywhere.

So, there special room actually foundation is isolated everything is isolated no vibration coming from anywhere, total insulation and Anechoic chamber is where you will find out the machine characteristics, Anechoic chamber I am not discussing them in detail Anechoic room no echo and reverberation room they just opposite all it was all reflection all reflection here no.

So, this is where you test machines for their directivity how much noise do they generate because you want to find out that noise generated by the machine not there, but you cannot do it in open field because there will be other kind of disturbances. So, that is why these kind of rooms are ok, real rooms are semi reverberant semi reverberant right real rooms are semi reverberant rural rules are semi reverberant and that is the diagram.

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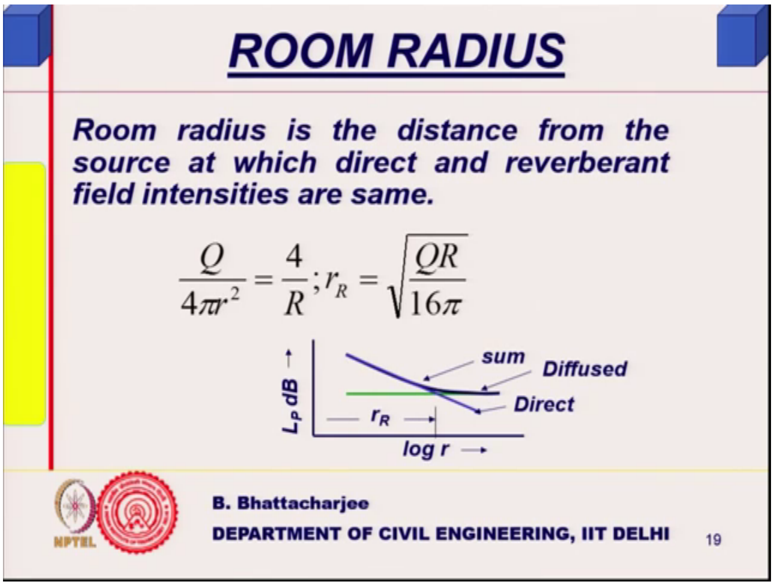

Direct sound reduces with distance reverberant field remains constant. So, this is your diffused field and actual curve becomes like that that is what we have seen and this is your sum this.

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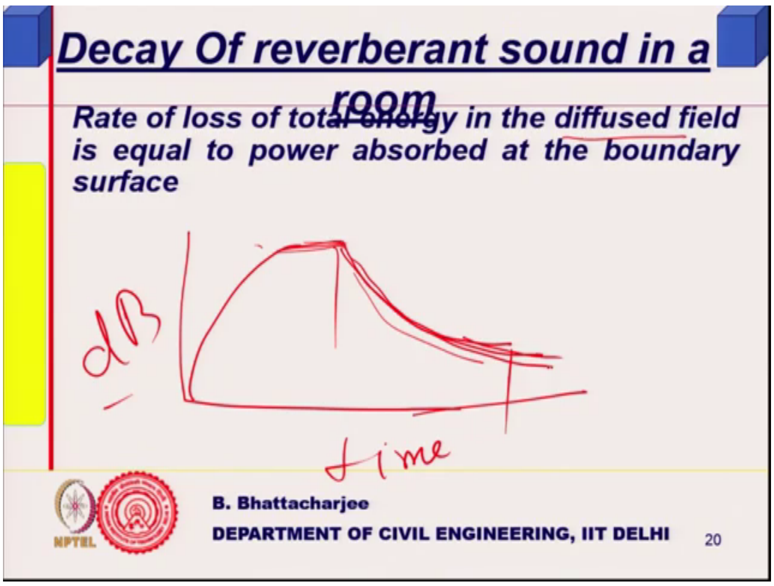

Is your room radius just quickly will define certain things, now it is important, 2 things are important so, if I want to have noise control within a room and noise is generated in the room itself then I will go close to anechoic behavior or less reverberation I would like to and if I want the sound to persist or you know it is a good sound then I would like that it remains for a longer period of time kind of. So, depending upon the type of type of sound that is generated or a type of room the functional use of the room I might like that sound persist for or sound remains reverberation remains or reverberant field remains.

So, we talk in terms of rate of loss of energy in the diffused field right we talk in terms of because I said reverberation is the phenomena persistence of sound in the room even after you have put off the source right. So, this is important how much is a rate of loss. So, once I have put it off we collect that it will be steady then it will go like this right, it will build up like this steady and then it will go like this, it will go like this right.

So, this persistence is important for me this part of the curve this is time versus level you know dB values. So, this is important for me some cases I would like it to be there some cases I do not like it at all so, but it is important. So, this rate of loss of energy from this diffused field because direct field I have cut off I put off the direct field. So, it is the diffusion reverberant field that will remain. So, rate of loss of this sound from a diffused field is an important issue and this rate is depending upon the boundary absorption in the boundary.

First one to go away direct sound goes away then the first reflection will stop, the one which started long back will still continue to come you know nth reflection will still continue to come. So, that is why this sort of a curvature. So, we would like to study how it is. So, the energies lost at the boundary of the surface from the diffused field boundary of the surface absorbed at the boundary.

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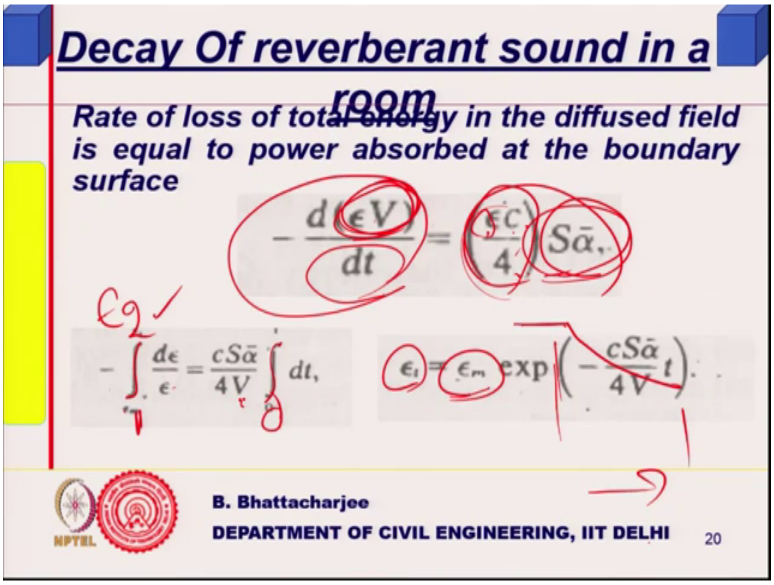

So, epsilon V is the total energy in the room. So, rate of change of this energy because it is negative because it is reducing down what was this? This was incident upon all the surfaces S alpha bar is absorbed this is energy density c by 4 this intensity right multiplied by this is. So, this is a total reverberant field energy epsilon R into V, epsilon R into V is a total because energy density multiplied by the total volume of the room. It is rate of change dt is equals to intensity this is the power per unit time I mean power so, energy per unit time.

So, rate of change of power must be equals to it. So, we are only talking of the diffused field this is the intensity of the diffused field, multiplied by S alpha bar that is lost at the surface. So, rate of loss at the surface is given by this. So, therefore, if I extend this integrate it you know V, I can V I can take out to this side and d epsilon by epsilon coming in here this is a minus sign c S alpha bar by 4 V and dt. So, this would be you know 0 to some value whatever value I want and it was the initial to some final value initial was this value then there is some value final value I am I can find out and time of course, it was function of time.

So, I can find out the rate of decay of the sound and as you can see this will be l n epsilon 1 by you know epsilon 2 because there is a minus sign. So, it is l n epsilon 2 minus l n epsilon 1 minus epsilon 2 because this is epsilon 1 let us say and this is epsilon 2 epsilon you know if. So, I mean you know that is going from initial to the final and this then could be written as initial at any time epsilon t epsilon n is equals to e to the power you know if I integrate this let me just do it for you full fully let us do it actually completely let me do it.

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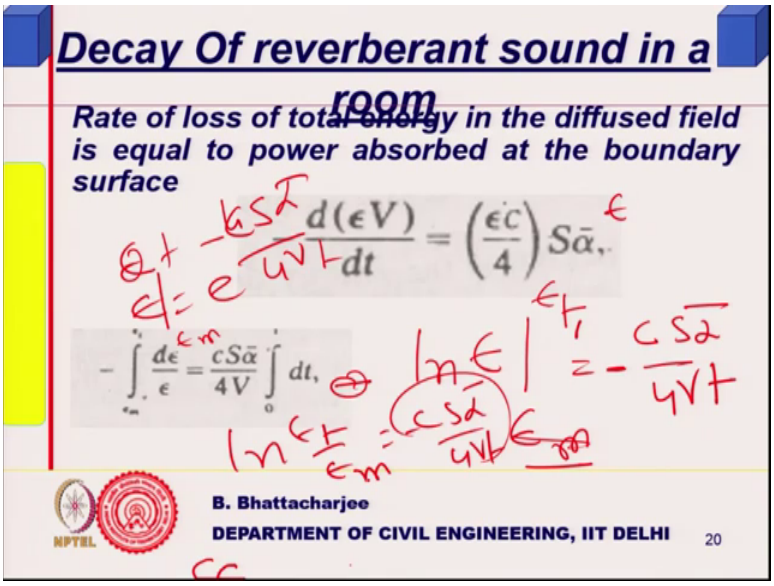

So, this will be l n epsilon going from epsilons initially that was there to some epsilon t there is a minus sign will come here and this will be c S alpha bar by 4 V t right.

So, this I can do one thing I can put the minus sign here this is one way of doing and then it will be simply epsilon you know l n e to the epsilon, epsilon it will be simply what epsilon you know epsilon and then you know like this will be e to the power let me put this on later on. So, it is epsilon is equal to epsilon going from epsilon starting to epsilon at time t is equals to e to the power minus 4 for you know c S alpha bar by 4 V t.

So, that is what it would be. So, you know it is. So, epsilon t minus or epsilon you know this can be written, how do I write, l n epsilon by epsilon what t by epsilon m l n epsilon t by epsilon m will be equal to minus c S alpha bar by 4 V t that is what after integration is. So, if I put e to the power all this it will be epsilon t by epsilon.

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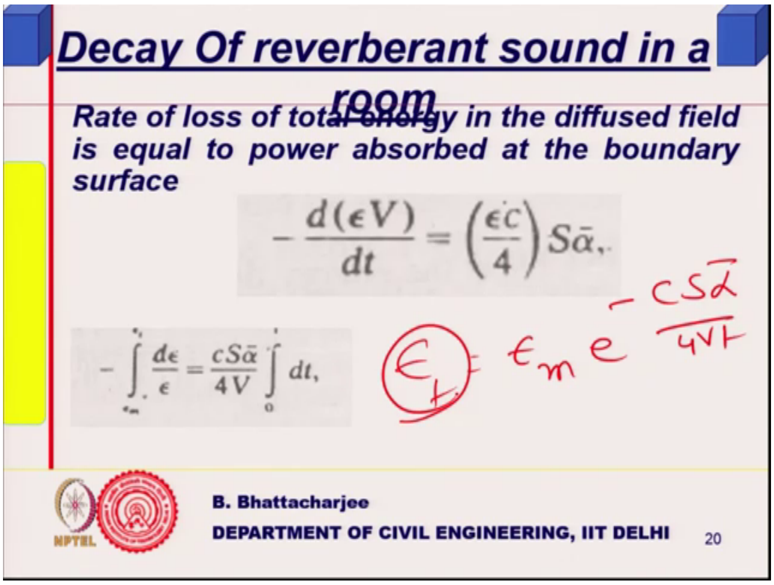

So, epsilon m epsilon t can be written as epsilon m multiplied by epsilon t can be written as epsilon m multiplied by e to the power minus c S alpha bar by that is how it would be you know that is what is. So, that is what we have done right that is what that is, what one can write, that is what one can write and this is what is written. So, you see at any point of time the energy density you can find out from the now I just define the last point for this you know this time the last point is. So, this is a relationship.

So, epsilon t at any time t is epsilon R starting just after you know you have put of the switch e to the power all this term is a function of minus t e to the power minus t that is why the curve is something like this, now I can define a time it is very difficult to actually fix time because it is related to a starting point also. So, epsilon t by epsilon m I can define this ratio the time required to reduce this from it is original value to some value.

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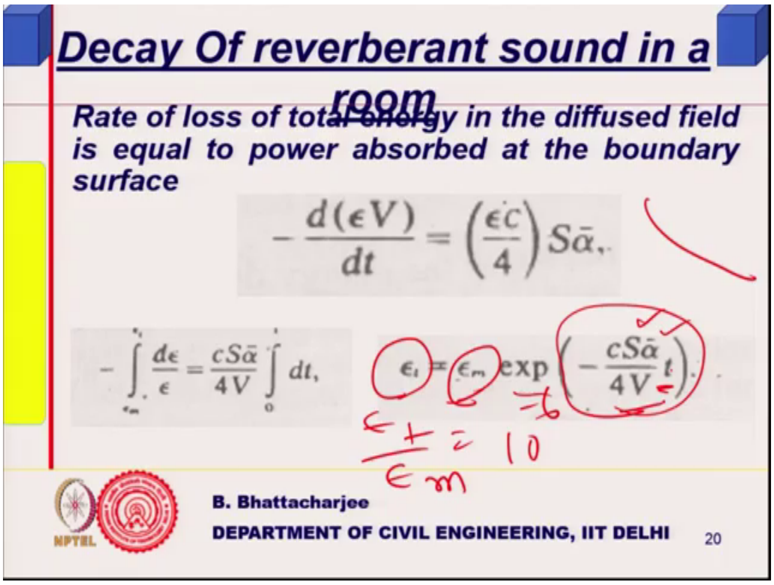

So, what we define, we define in terms of that when this ratio become 10 to the power this is bigger right this is smaller 10 to. So, this should be equals to 10 to the power minus 6; that means, when the sound reduces to one millionth of it is original energy density value, that time I can consider as a standard time showing the characteristics of the room because these are this is related to the room S alpha bar V this is related to the room.

So, how good the room is in persisting the sound or keeping the sound or dissipating the sound that I can find out if I know epsilon t by epsilon m some ratio it is taken as 10 to the power minus 6 right.

So, the time required for sound to reduce for it is original value to one millionth of it is original value is called as reverberation time right we will talk about this more in the next class.