Biomathematics

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Lecture No. # 19
Diffusion

Hello, welcome to this lecture of Biomathematics. We have been discussing about diffusion in the last lecture, where we use the ideas from vectors and calculus to derive the diffusion equation.

We said that, just by taking the continuity equation, that the current from one side to the other side and you think about the current, we said that for the concentration to change at a particular place, whatever the current that is the flow that is coming in, has to be, cannot be equal to the flow that go out, if they are equal, the concentration at this point will not change and from this just simple or common sense arguments.

We use mathematics, which is we called we said it is like a language, so we use the we use mathematics basically to express this idea that the current that flowing in has been different from the current that is flowing out, for the concentration at a particular point to change and from this simple argument we derived an equation and that is the diffusion equation, that equation governs the diffusion of particles as we discussed.

Today, we will discuss a little more about diffusion there are very important relations that is related to diffusion. So, we will discuss some very important interesting results associated our resulting from this equation, which are related to diffusion.

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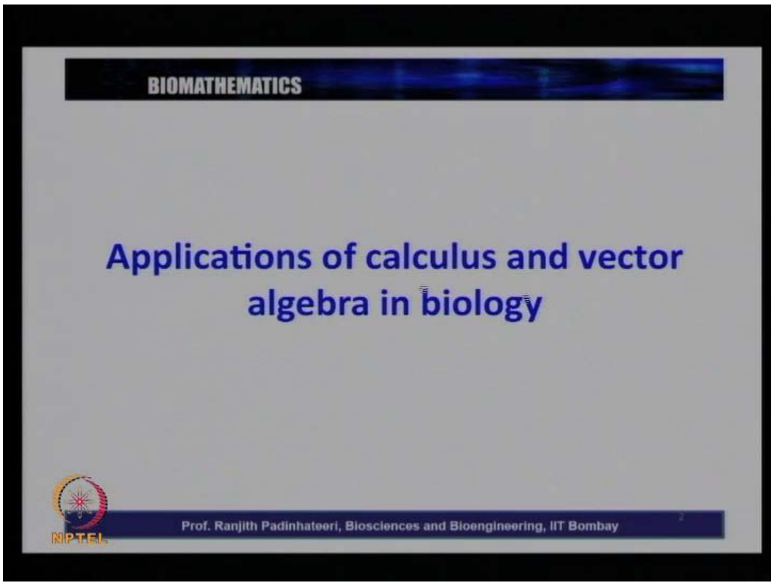

So, today's lecture is basically again related to application of calculus and vector algebra in biology and we will again discuss diffusion.

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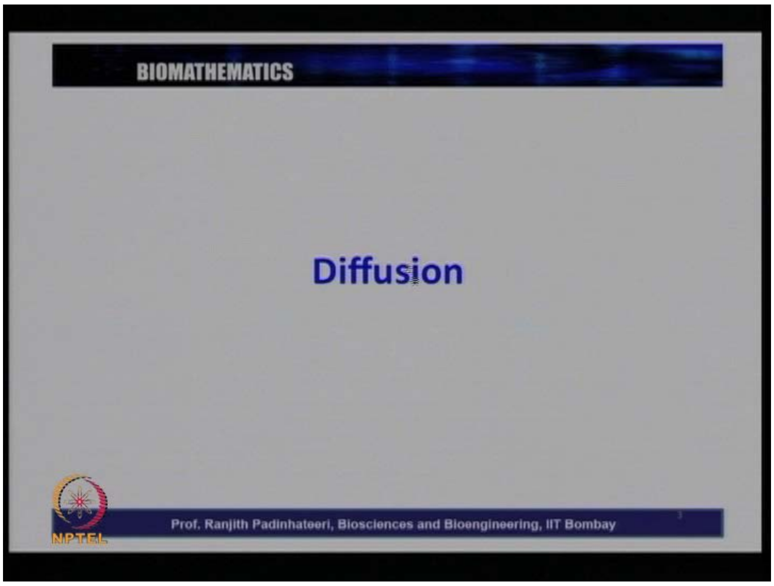

So, today again we will discuss the, we will continue discussing diffusion and we will derive some interesting results, interesting expressions that related to diffusion based on what we learnt so far. These are very important relations, very famous relations, very useful in biology or and in many of the fields.

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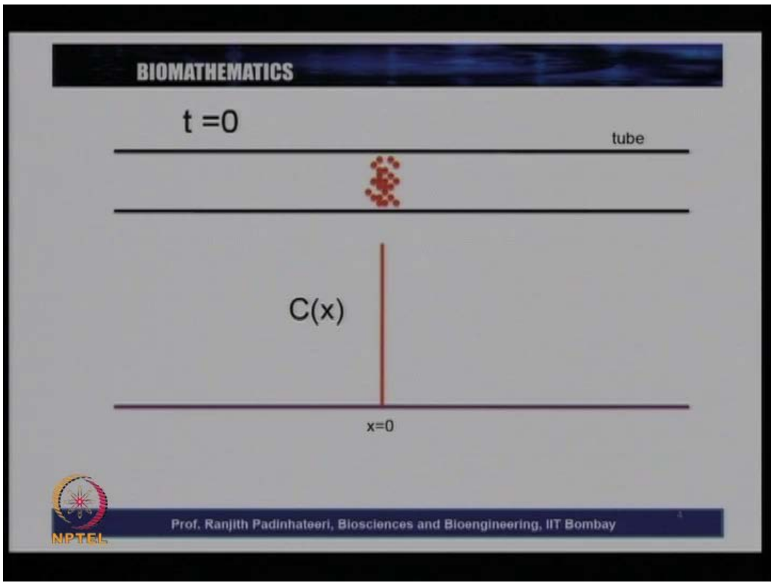

So let us just started, so we said that when you so what is shown here is the tube. So, you have a tube at and this long tube, and you introduce some particle at some particular position, let us call x has the length along the tube, so this is the x equal to 0 and this is x equal to 0 and as we go as x will increase and x is decreasing. So, let us think of this an x axis and there is in this tube we are introducing, let say we are putting some ink molecules and there is imagine there is in a water in this tube, and we are introducing some ink molecules or protein molecules in this tube, so that is shown here.

And what is shown at the bottom here is, the plot of concentration as function of the x, so this is an x equal to 0, so at this moment the concentration is only at x equal to 0. Some what almost like a line up we may be a little more width, but essentially is just a line like a line up, so which says that the concentration is only, the concentration everywhere else, here everywhere the concentration is 0 and the concentration is non-zero only at x equal to 0.

Only here you have particles and here, here, here, here, here no particles (Refer Slide Time: 4.15). So, this is what, this picture is written in kind of a in the in the form of a graph here, that is what is shown here, whatever shown here is written in the form of a graph here. Basically what you have here is that the physical picture is that, you have a tube and the middle of the tube you have some protein molecules. Some concentration the concentration protein molecule is only at x equal to 0 and no where else you have this protein molecule.

How do we represent this kind of a thing mathematically, what is the is the equation that you will write for representing things of this fashion in a mathematical form. So, we said that anything that we speak or any idea that we see or any physical idea we can represent in the form of equations and that is kind of a language in itself. So, how do we how do we say this mathematically, the fact that you have only concentration at one point and everywhere else it is 0, it is shown graphically here just a line here and everywhere this is 0.

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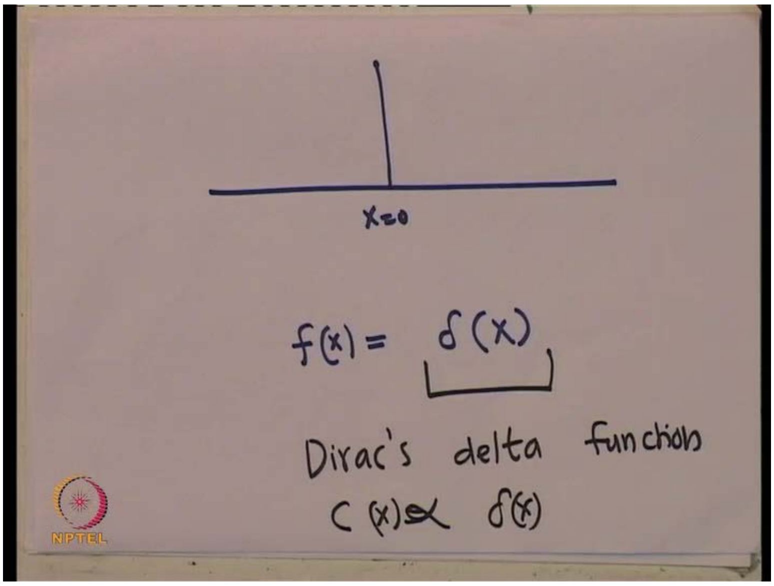

So, there way to show this mathematically it turns out that, so if you have x equal to 0 and you have only at this particular point. This is shown by, so this is a function and it turns out this function can be written as delta of x, so this delta this famous function this is called mathematics, this is called dirac's delta function (Refer Slide Time: 5.50). Basically this represents, this represents, and this is basically precisely to say what we just said that you have only something only at particular point everywhere else this is 0.

There are some particular properties for this, for the dirac's delta function we would not go into this, but what I am trying to say is that you can represents this mathematically using this delta function. So, the concentration that you see here C of x, if you wish can be written as a derived delta function; C of x can be written as, so you can say C of x is proportional to is directly proportional to the delta of x is like derived delta function, so this is a way of telling this mathematically.

So, now let us let us think about, let us think physically for the moment let us just keep the mathematics apart for a moment; and so we know that, you have a tube here and we have some protein molecules here and there is water in this, you can think of this is protein molecules or even ink molecules or any molecules here, and we call it at time equal to 0 this is what is the thing you see.

Now think of this as the time goes, what will happen let say after 10 minutes, if you look at this tube what will you see, you will see that this molecules would have diffused this way and this way, they just diffuse this way and diffuse this way, so they would have diffused either along this tube (Refer Slide Time 07.58).

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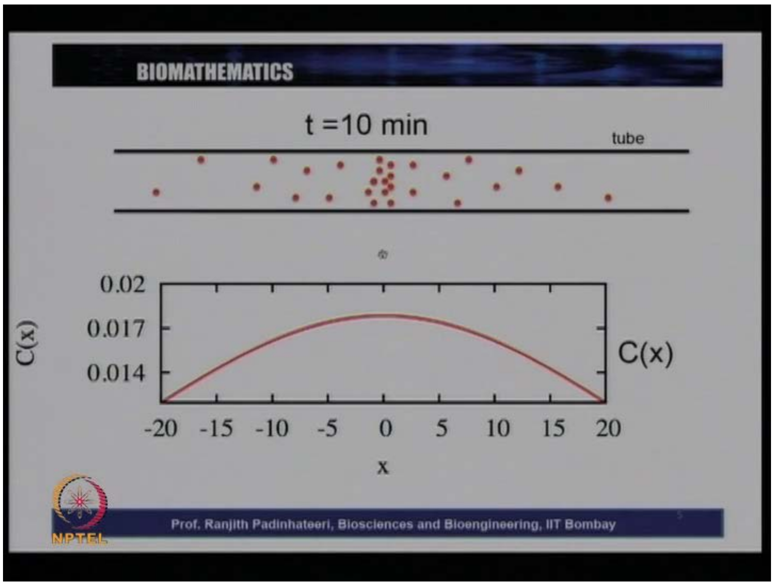

So what do we see, you will see this; look at here they have diffused along this way, so there are some molecules here, some molecules here, but still majority of the molecules here (Refer Slide Time: 08.20). So, this is what you see after 10 minutes, 10 minutes you after 10 minutes you see that there are many molecules still at the center, at x equal to 0 and many molecules of few of them are here and few of them here and if you represent this graphically, we can represents this particular way the concentration if you plot as the function of x.

What you would get is that, at faraway the concentration is very less and at the middle the concentration is large. So, forget what the form of this curve, what is the equation here, but there is some particular form this a mathematical, this graphically, this concentration can be represented by particular graph, that is it is the it is a peak at the middle; that means, still majority of the molecules are in the middle, very few of them are towards the ends as you go along far away from the center either to the left or the right.

You have fewer molecules and there is no particular reason that right is end different from the left, because if there are two of them 100 of them, 20 of them diffusing to the right, you might as well have 20 of them diffusing to the left and there is no symmetry, the symmetrically, they are symmetric; like left and right are symmetric to each other there is no particular reason that left is different from the right on this on this on this particular tube.

So, therefore, the concentration on average on the left and the right will be the same, there is no particular reason that more of more will diffuse to the left or more will diffuse to the right, so this function will be symmetric along x equal to 0.

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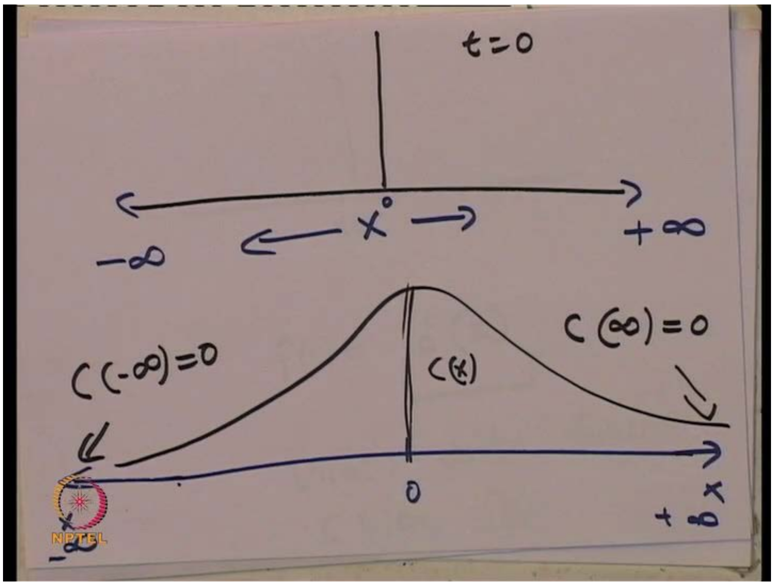

So, you have a function which is essentially, so you at begin to, begin with you had this x axis. So, this is x going to, if you go if you think of this plus infinity and this is so this is plus infinity and this is minus infinity, let say this is x is going this way to begin with you had just one line as a concentration (Refer Slide Time: 10.48). So, this was a concentration to begin with, so this is t equal to 0; now, as the time went as a time went the concentration, so if you take this x axis, this is minus infinity this is plus infinity this is 0 so this is 0 here (Refer Slide Time: 11.24). What you would see is that, you would see the kind of a nice symmetric thing like I mean, this may be what I drew may not be perfect, but I wanted to have the peak at 0, here is peak at 0 and symmetric about this; as it goes to infinity, so this is the concentration as a function of x, as it goes to infinity the concentration will go to 0. So, at you know that the in the tube if you look at the tube here, far away at infinity you will not find anything after 10 minutes, because it would have it would not have yet reached infinity.

So, important point C, at you look at here, C at infinity is 0; C at minus infinity is also 0 so that means, here and here the concentration will slowly, is a is actually is 0 faraway in the concentration is 0 and at the middle you have maximum concentration. So, you have why after 10 minutes this is what we expect, but the important point note is that at infinity C at infinity C at minus infinity as to be 0.

Because, you can imagine after some 10 minutes the concentration it would not have residue infinity, it would not it wouldn't if you look at distance far away, if you would not look at far away distance it would not have yet reach that far. So, the concentration that has to be 0, so by knowing just this then it has to be symmetric and that the concentration the molecules would not have reached at infinity or far away.

We can derive very interesting results this is some two results physical things we have to know that after it will have a such a shape and it will have a symmetric shape around x equal to 0 and that concentration will be 0 far away I would not have reach there. No molecules would have reached far away from the initial position if you look at, far away from the initial position after 10 minutes molecules would not have reached there; after any time after finite time t it would not reach 5 some infinitely for distance.

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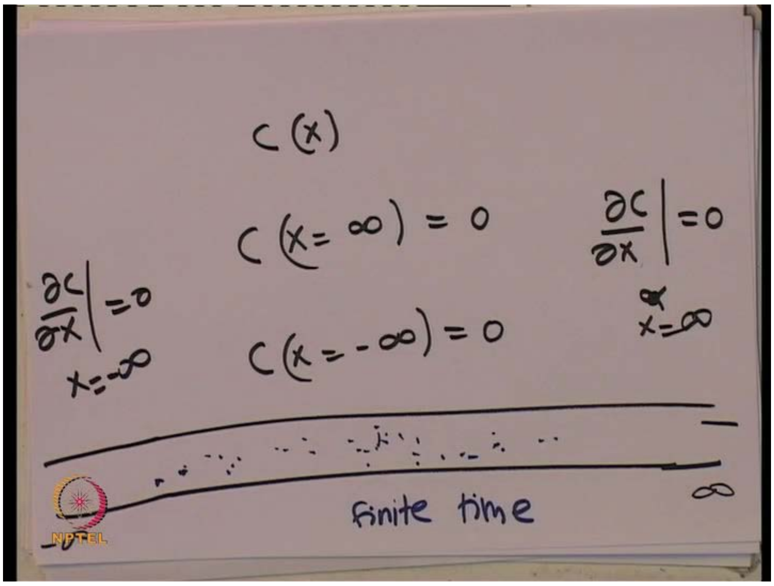

If you know this much we can derive some interesting, so what did we say, we said that we have, why did we say, we have some concentration and C at x equal to infinity is 0, C at x equal to minus infinity is 0, what is this mean, if you have an a pipe; you if you had a pipe like this and if we had some molecules here, after any finite time they would not have reached far away infinities and minus infinities here the concentrations will be 0 here also the concentration will be 0 there will be still diffusing somewhere near the initial point.

So, this is finite time, at any finite time after 1 minute, 2 minutes, 3 minutes, and 4 minutes, even after 10 minutes it would not have gone that far, it will be still at a finite distance x the concentration.

So, knowing this much idea, so you know if you know it would not have reach the derivative let say del C by del x at x equal to infinity this will also be 0, because there is no molecules here see itself is not there, so C C cannot vary their, because C does not exist there. So, del c by del x will be zero here also del c by del x at minus infinity when x equal to minus infinity this all be 0, because there is no molecules. So, the change in concentration will be anyway 0 (Refer Slide Time: 16.03).

So, if you by knowing this much idea we can get some interesting results. So, let us go and do this.

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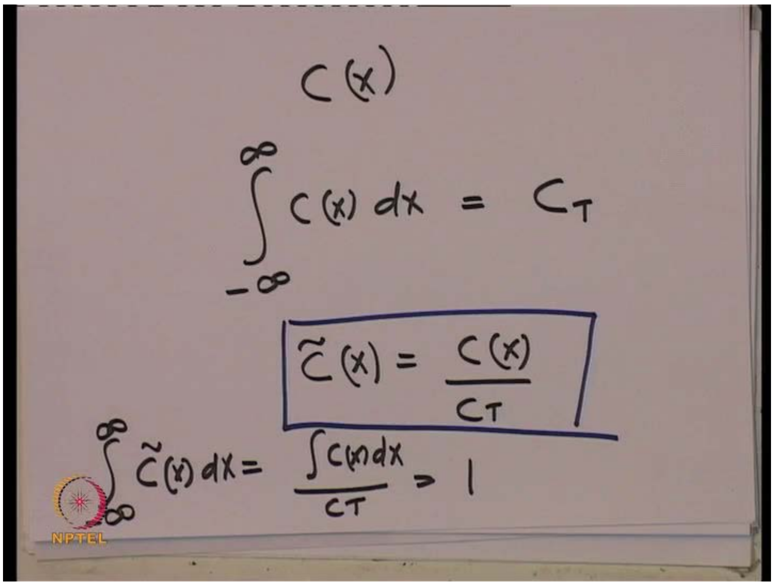

So, now let me do some small, let us let us discuss another interesting fact. So, we know that we have a concentration C of x. So, what is integral C of x d x, so at every point x you have this concentration C; so now, what you are doing, your doing summing over all the concentrations along x. So, that is integral C of x d x, so what is this, as to be the concentration C T, this is what total concentration C T, because this is the now for simplicity for a for a, now let me define as someone new function call C tilde of x, which is C of x divided by this constant C T just for some convenience I am doing, this is just a trick yes for convenience I am doing this.

So, if you have such a function what will be integral minus infinity to infinity C tilde of x d x, this will be integral C of x d x divided by C T we know that integral C T integral C of x d x is C T from here, so this will be C T by C T this will be 1. So, we have this new function let us define, and this function called C of C tilde f x, which is C of x divided by some constant number which is the total concentration. So, what is the C tilde of essentially? This is the fraction in some sense concentration divided by the total concentration.

In some sense you can think of this is a percentage, a fraction or in some sense this is like a fraction, but does not matter what is that mean, it is just a trick we have this concentration we divided by a constant, we can always divide by a constant we can always divide by a constant mathematically nothing changes and we have a new functions C tilde of x.

So, we did some tricks we just did realize that integral C of x d x is total concentration and we define a new function call C tilde and we called it C of x by C T, such that the integral C tilde of x d x is 1; that means the total integral of this becomes 1. We have C tilde of x now, let us go back to the diffusion equation.

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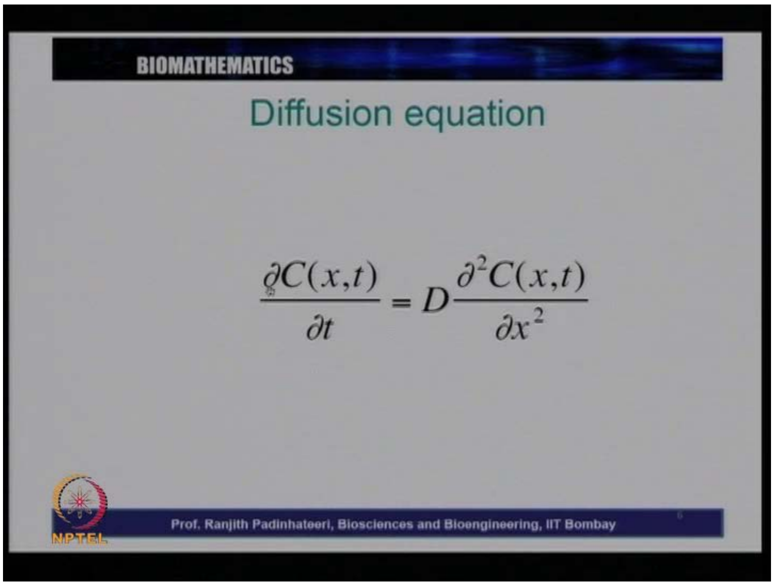

So, what is the diffusion equation, diffusion equation is this equation that we describe last time that del C by del t at any point x and t at any point x, at any point time tiny at any point x at any time t is equal to d del square C by del x square. So, the change in, the how does the concentration change with time is this, and how does the concentration change in space, x is the distance space variable.

And this is essentially, this is essentially how does the concentration change with space and how this space change with time, concentration and how does the concentration changes with time, so this relation is called the diffusion equation. Now, let us look at a few properties that we define last time, we define x average.

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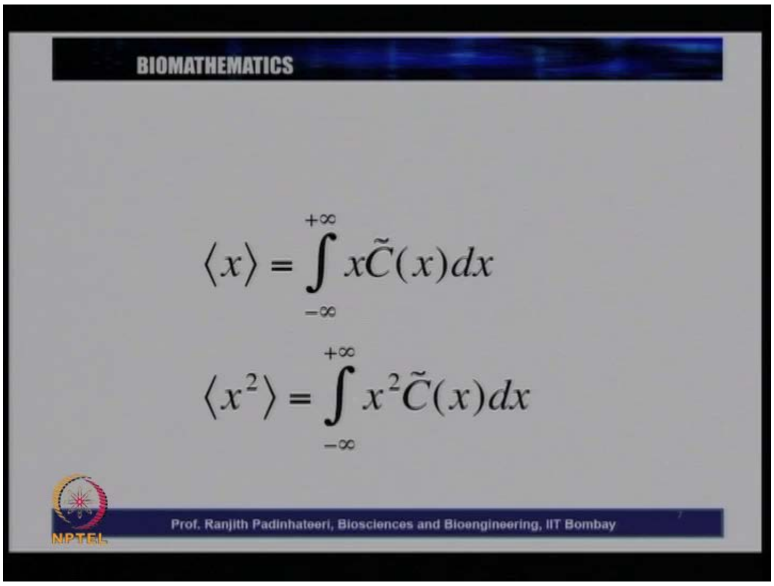

So, here x average is integral x C tilde x d x, so c tilde we just define its concentration divided by C T. So, this is some kind of a normalize distance, do not worry about this, so this is, the let us define some properties quantities called x average and x square average.

What is this essentially mean we will discuss this, we will discuss what is this essentially mean, what is this physically mean, but we can always define x average and x square average is in this particular manner. So, if you do this x into C tilde of x d x and x square into C tilde of x d x we get this x average and x square average.

Now, the aim of this is that, the aim of this is to derive some interesting results related to the rms distance of diffusing particle, root means square distance. So, this is the definition of x square average, so typically you know you might have seen at many places that you might have heard of rms velocity, rms where a root means square velocity, what is a root means square velocity like think about a we had, you had gas in a box and this gas molecules where freely moving in all directions.

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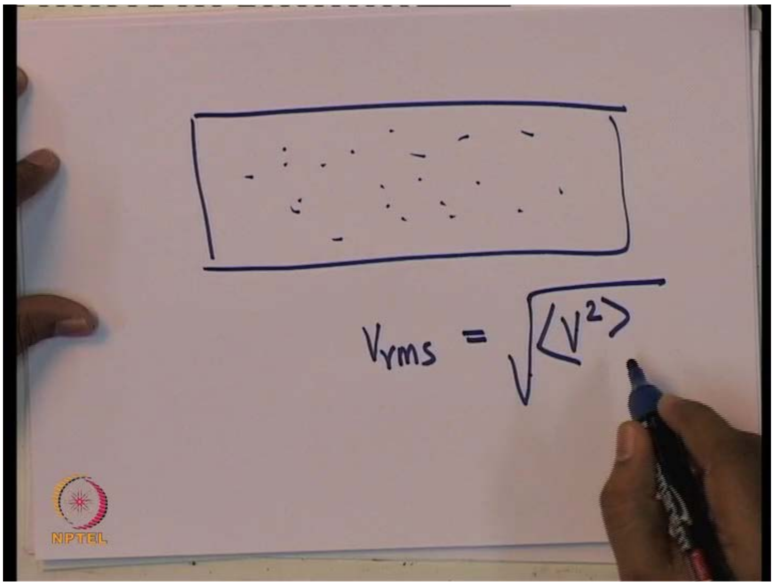

This ideal gas we had and we could calculate and in such cases, you might have studied that V rms the root means square velocity, this is related to the r t and temperature and all that a this is related temperature we have resign something called as rms velocity.

So, the definition of this is that V square average this is root, there is a mean this is mean sorry this is square mean, mean square, so and this; this is the definition of rms velocity you have find the root mean and square root mean square.

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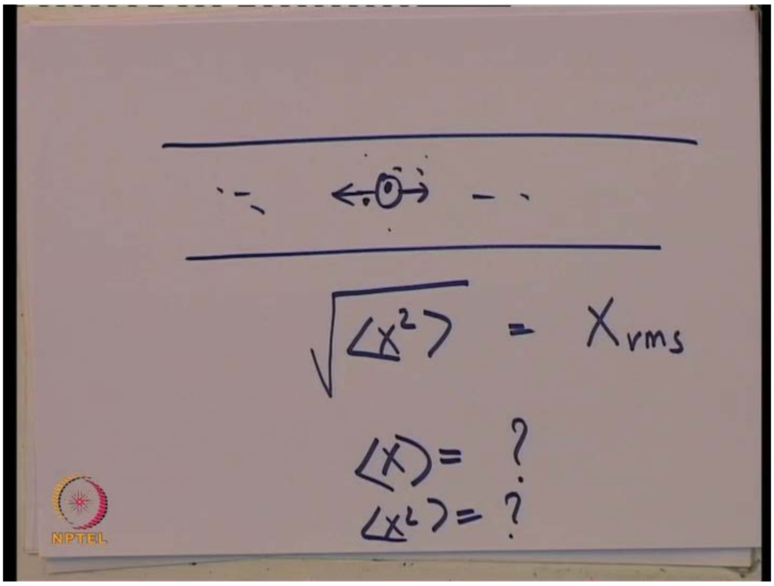

Similarly, here you have particle in a tube going this way and that way there diffusing and what we want is x square average root. So, this is you can say X rms, rms distance the root means square distance that this particle will diffuse with time, like if you wait 10 minutes what is the root mean square distance this particle diffuse (Refer Slide Time: 23.04).

So, let us think about just one particle here, look at this one particle this one particle will can go little here then into here, so on an average you also can find out how much what is the average distance and what is x square average this is what we want to find out and this what we are defined here (Refer Slide Time: 23.32). So, let us define, we have defined x average and this and x square average as this.

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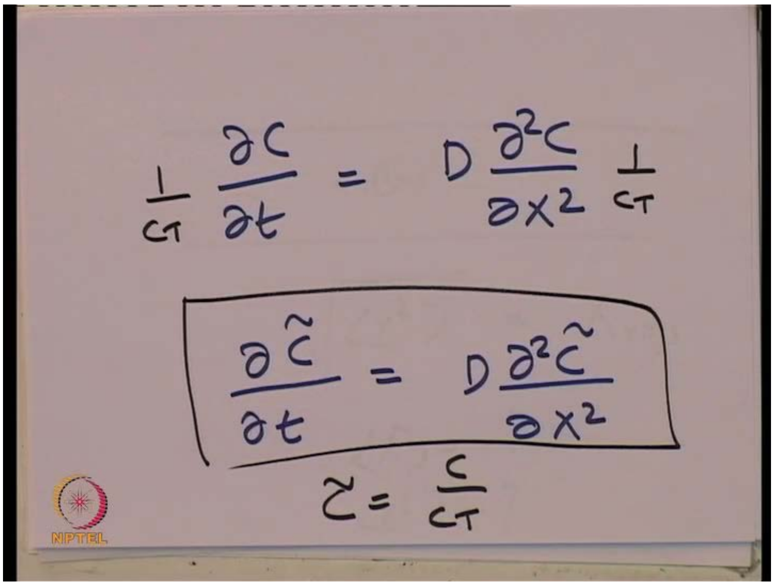

Now, let us calculate this, now how do we calculate. So, we had this diffusion equation which is del C by del t is D del square C by del x square, I can divide both side by C T, so C by C T is C tilde a, so I can write this as del C tilde by del t is del square C tilde by del x square or C tilde a it defined as C by C T you just divide here by a constant here also by this C T both sides, so I divide by C T here, I divided by C T here, so I divided by C T here I divided by C T here, since it is a constant I can get this equation, so now, we have this equation (Refer Slide Time: 24.38).

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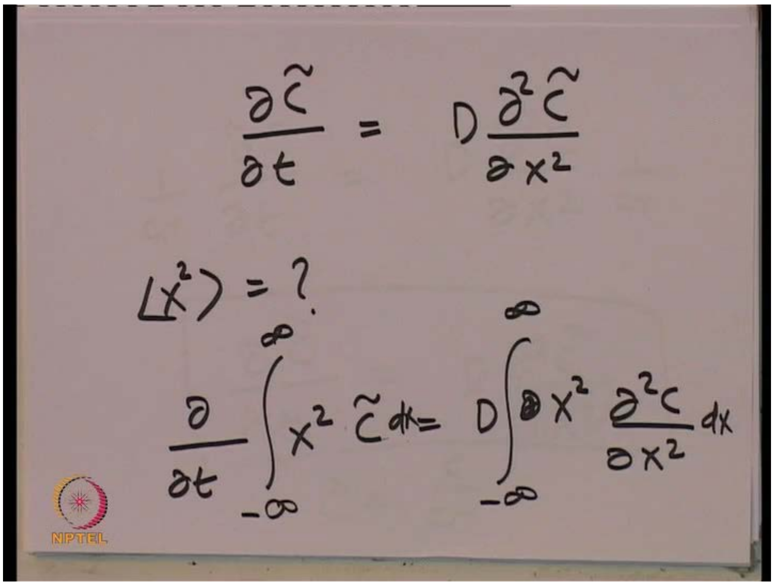

So, now that we have this equation, del C tilde by del t is equal to D del square C tilde by del x square, I can multiply both sides. So first, let us first calculate x square average. I can multiply both sides with x square and integrate. So, let us do this, so there is del by del t I multiply with x square and there is C tilde and is equal to D del sorry I have x square I multiply and I have del square C by del x square and I integrate both from minus infinity to infinity d x d x. So, what did I do, I just multiplied both sides with x square and integrate it both sides, nothing will change, I multiply both sides with x square I integrated both sides with respect to x.

Now here, the derivative is with respect to time, and this is the partial derivative, so does not matter whether I take the derivative outside and the integral is with respect to x, so if the integral is with respect to x, you can take this del by del t outside, because the result of this is anyway as nothing do with time.

Sorry this is independent, this is only depends on x, so I can, whether I write x square del by del t inside or outside it does not matter, because the integral is only with respect to x and this is a partial derivative, so I have this kind of an equation.

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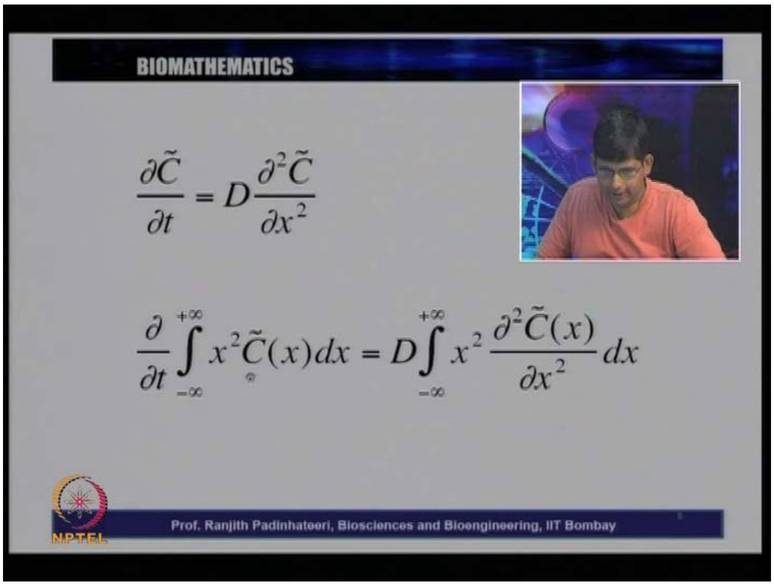

So, what do we have, I multiply what did I do, I had this equation; I multiplied both sides with x square and I integrate it with d x, this what I did. So, let us write it down once more to be clearly.

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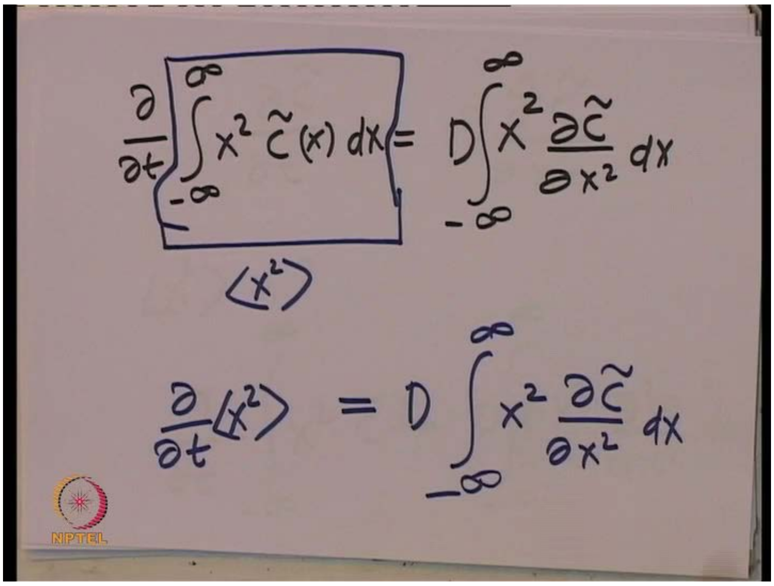

So, we had del by del t of integral minus infinity to infinity x square C tilde of x d x is equal to D into integral minus infinity to infinity x square del C tilde by del x square d x, this is what we have.

And this is what precisely we have it here, now what is this part, what is x square C tilde of, what is this? We just learn the, we just define this as x square average. So, this quantity, which is just defined this quantity as x square average, this quantity what I what I put in this in this, around which I due to this line I have, we just define this as x square average.

So, the left hand side is del by del t of x square average. So, now, what is on the right hand side we have this, now you have some function x square, some other function del C tilde by del square (Refer Slide Time: 28.41). So, you have two functions, which depends on x and you have to find out the integral of this, we have minus infinity plus function x square and another function del C tilde by del x square d x.

So, now we have to find the integral of this, so something that we learned in calculus, we have to make use of this to get this. So, what did we learnt in calculus, so there is an interesting relation that we learnt in calculus that we can make use here.

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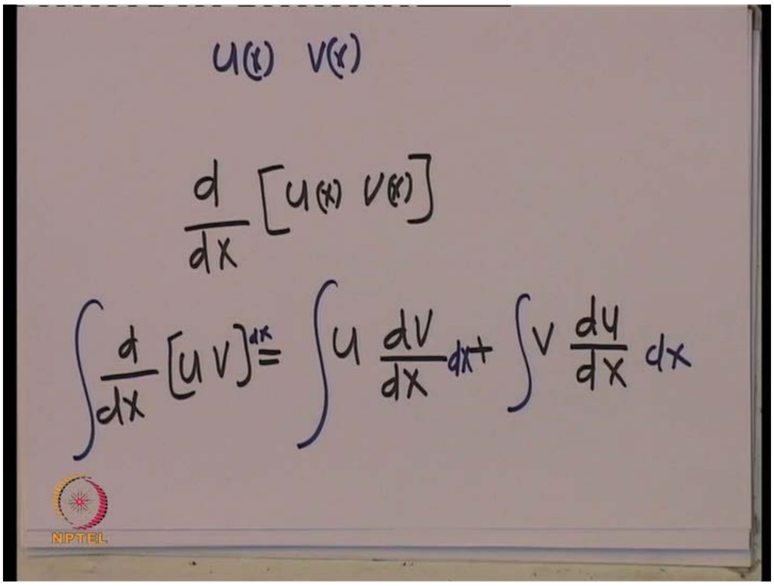

And what is that, so we defined, we learned that if we have two functions u and v, the you have u of x and v of x we learnt, that the derivative, we learn something called product rule; the derivative of this we learnt we learn that d by d x of u v is u into d v by d x plus v into d u by d x, we learn this in calculus, this is called we call product rule.

So, that is derivative of product have two functions is, first function with derivative of the second function plus second function into the derivative of first function, this is what we learnt. Now, we can integrate this just like this, so we can just multiply with this and integrate this and we can write this d x here. So, we can just integrate all through out and get a relation, we can say u into d v by d x is equal to, so we can write.

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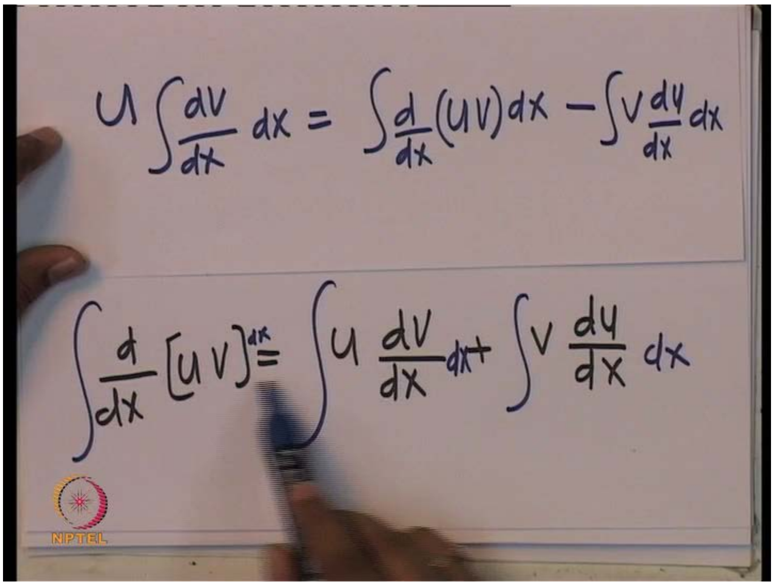

So, what can I write, so look at here, so I can write u into integral d v by d x d x is equal to, so this is equal to integral of d by d x of u v, d by d x of u v d x minus I take this side. So, I just rearrange this term I write this is equal to this minus this I can take this term this side, so u integral this minus, this term, which is in integral d u by d x d x, d u by d x into d x. So, some we are just making use of, something that we learnt in calculus, that we use the product rule and using this product rule, using this product rule, look at here using this product rule we rewrote (()) integral and integral u d v by d x is this. So, in other words, I can rewrite this thing I can rewrite this thing, so you know d v by d x into d x you can write is basically, so let us write this little more carefully, u into integral d v by sorry I just made a small mistake when I wrote here, this integral has to be here, integral u v d v by d x, because what we had here.

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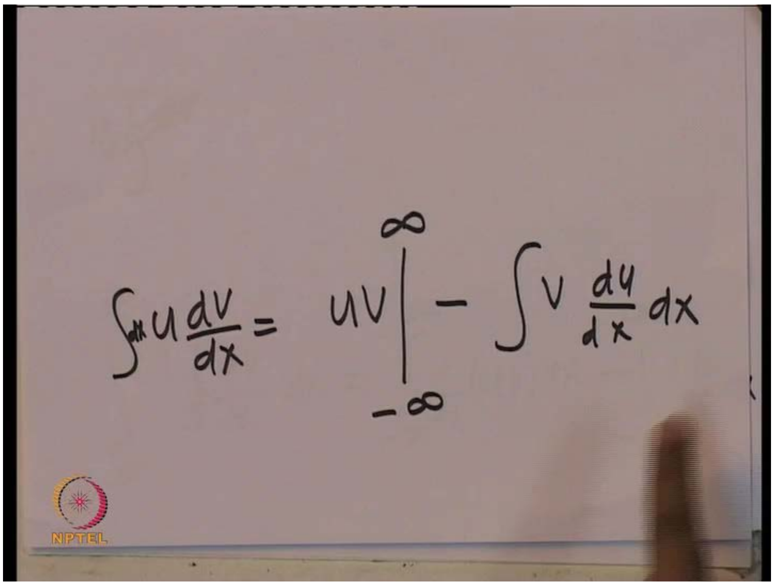

Integral u d v by d x is equal to d by d x of u v d x minus v d u by d x. So, when I write little more carefully I have write, so what do I write, integral u d v by d x is equal to d by d x of u v d x, so derivative of function integral of a derivative is a function itself, because you know integral we said is a anti derivative, so integral of d by d x of u v is u v itself, so this is essentially the u v in the limits.

So, if you have this integral if you have this integral from minus infinity to infinity, all these integral before minus infinity to infinity, if this integral from minus infinity to infinity, what you would have is in the limits, minus infinity to infinity; think about this, this is what you will get, you just carefully do this integral u v d v by d x into d x will be equal to u v minus integral v d u by d x into d x. So, this is called integrate by parts, you have any function u d v by d x you can write in this particular form.

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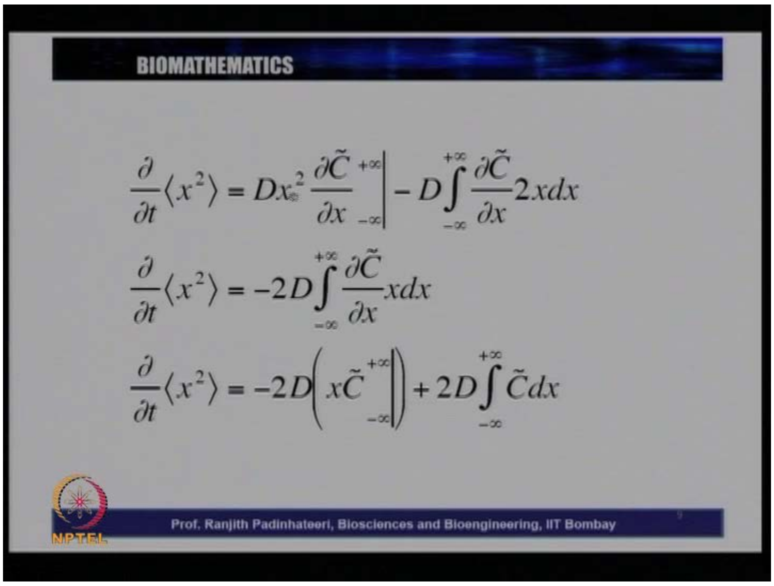

So, now look at this equation look at this equation, what do we have here what do we have here, we have in this side a function let us call this. So, what did we have here, we had we had an equation which is del by del by del t of x average is equal to integral minus infinity to infinity d times x square del C by del square C tilde by del x square d x this is what we had (Refer Slide Time: 34.53).

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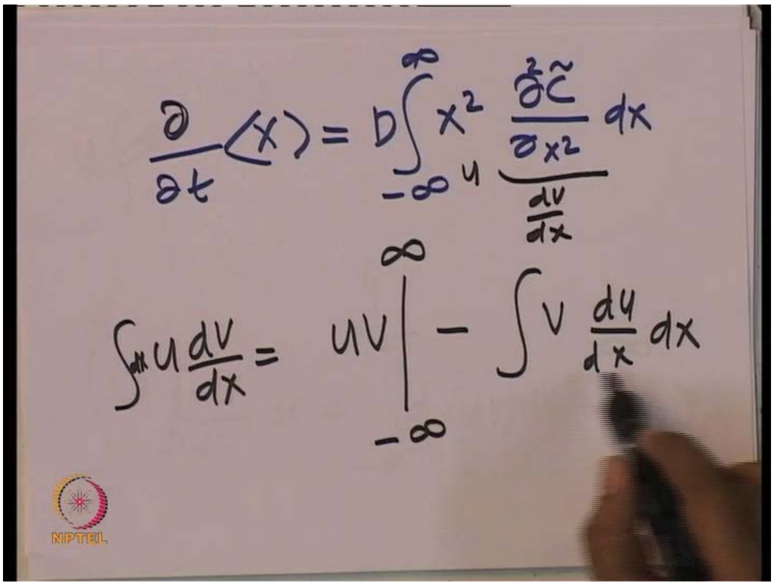

So, we can always define, this as u x square as u and this as d v d x, so let us take x square as u and del square C by del x square as d v d x (Refer Slide Time: 35.01). So, what is this, this will be integral u d v d x d x. So, you can use this formula now, to do this integration of this, so if you look at this carefully, let us write down, only the right hand side the right hand side if you write down the right hand side only.

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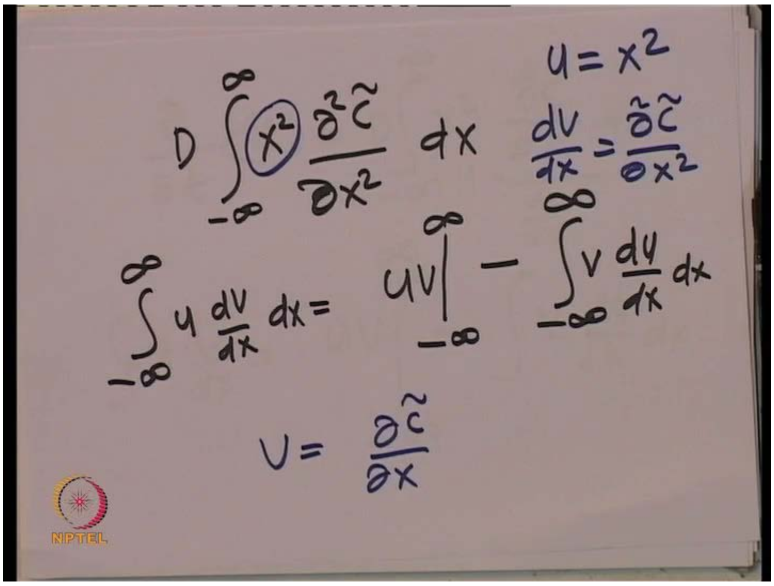

What do we have is that, D into integral x square del square C tilde by del square d x as integral, I call this x square as u and this as d v by d x into d x and we said that this is nothing but, integral u v in the limits minus integral v d u, V d u by d x minus infinity. Now here, u is x square, this we take as u and d v by d x is del square C tilde by del x square, so what is v, this is d v by d x v will be del C tilde by del x, so the derivative of this will be del square C tilde del x square, so you will get this. So, if you apply this formula and rewrite this integral, what you would get is the following, so look at here, so you will get u, which is the x square into v in the limits minus integral v which is del C tilde by x into d x del u v d u derivative of x square which is 2 x (Refer Slide Time: 37.08).

So, if you apply that formula, that is integrate by parts, do that carefully you will get exactly this, you apply that formula take x square as u and del C tilde by del x as v you will get exactly this formula (Refer Slide Time: 37.33). Now, what is the derivative at infinity and minus infinity, we said that the derivative at infinity and minus infinity there are, there is not anything, so this derivative at both the places will go to 0. So, this term will go to 0, because there is no concentration at infinity and minus infinity, there is no derivative also, because there is no change in concentration either because, there is not anything at all.

So, essentially or in other words it is symmetric, whatever in the left side as we equal to the right side. So, this term will go to 0 and this term will go to 0 and this, so what remains is just this, what remains is just this, so del by del t of x square average as to be minus, I take this 2 outside 2 D minus infinity infinity del C tilde by del x into x d x (Refer Slide Time: 38.25). So, you have this function now, now you can do the same way integrate by parts once more.

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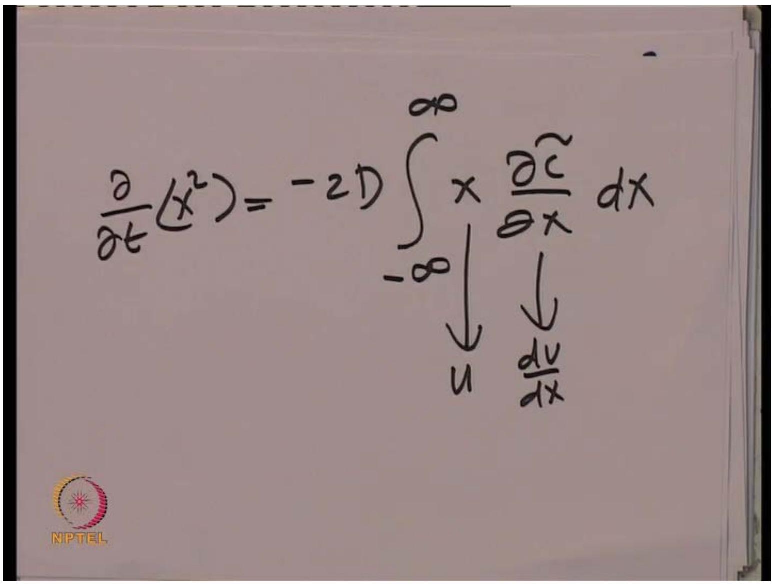

So, now let us see what we have in hand, what we have in hand, is that look at what we have in hand, we have in hand del by del t of x square average this minus 2 D t into minus infinity to infinity x del C tilde by del x d x again we can do this integrate by parts, we can take this x as a u and this as d v by d x or del v by del x if you want and you can integrate this five parts. By the same formula that we used and what do we get, what you would get is that again let us say x is u x is u, so u into v in the limits minus v d u, v is C tilde and d u is d x, which is one sorry which is the derivative of the x where d x by d x is one, so what you will get is 2 D into integral C of x d x. Again using symmetry is given is that, the concentration anyway at infinity will be 0, you can show that this term is 0.

Why is this 0, because the concentration at infinity and the concentration at minus infinity is anyway 0. So, this term has to be 0, now this term is integral 2 D, 2 D integral C of x C tilde of x d x. So, what we have essentially at end of the day, if you say that, we required this term to 0 because, the concentration at infinity and minus infinity is 0, so if you equate this term to 0.

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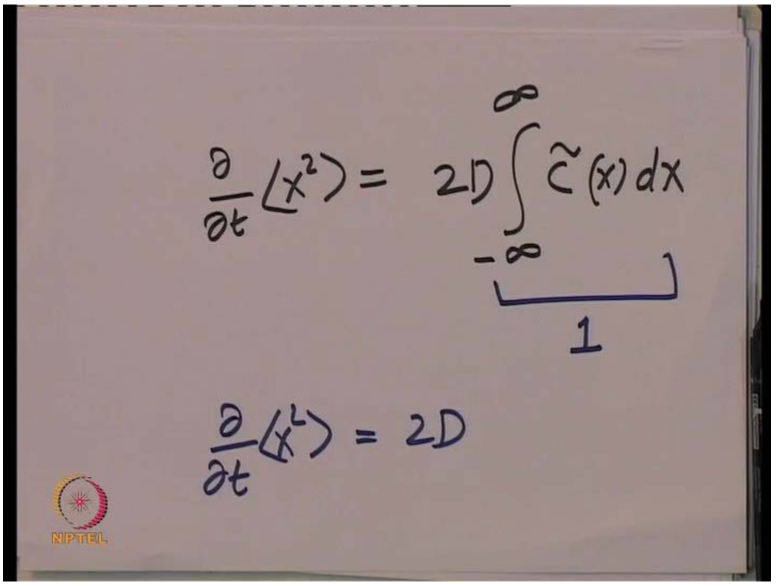

What you have is that del by del t of x square average is equal to 2 D integral C tilde of x d x minus infinity to infinity. At the beginning we said that, this is 1; that is the definition of C tilde of, we define C tilde of x such a way that integral C tilde of x d x is 1. So, now what we have del by del t of x square average is 2 D this is what we have. So, what do we have, del by del t of x square average is 2 D, so now let us integrate both sides and see what we get?

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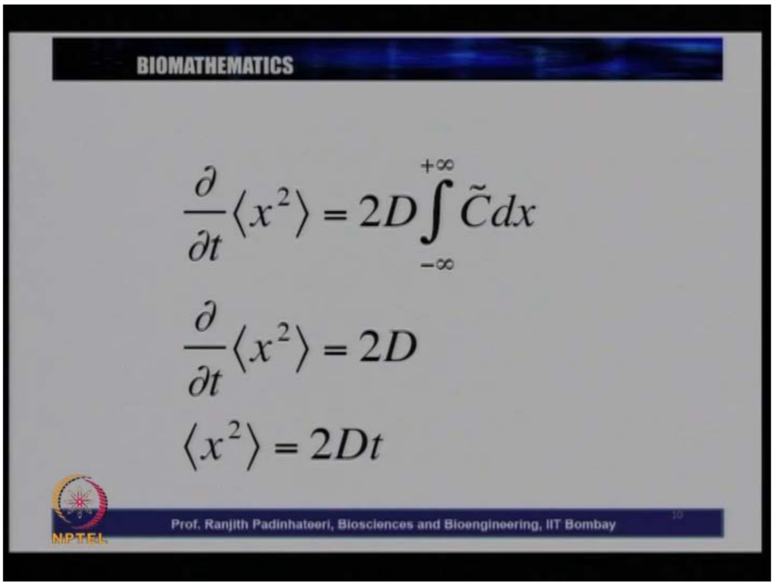

So, what we get is that, so if you have since this look at here since this is integral C tilde of f x d x is 1 we have del by del t of x square average is 2 D, so you have x square average is equal to 2 D t. So, you have x square average is 2 D t, this is a very interesting and very important relation, as well as diffusion is concerned very widely used in many context in biology and in many places.

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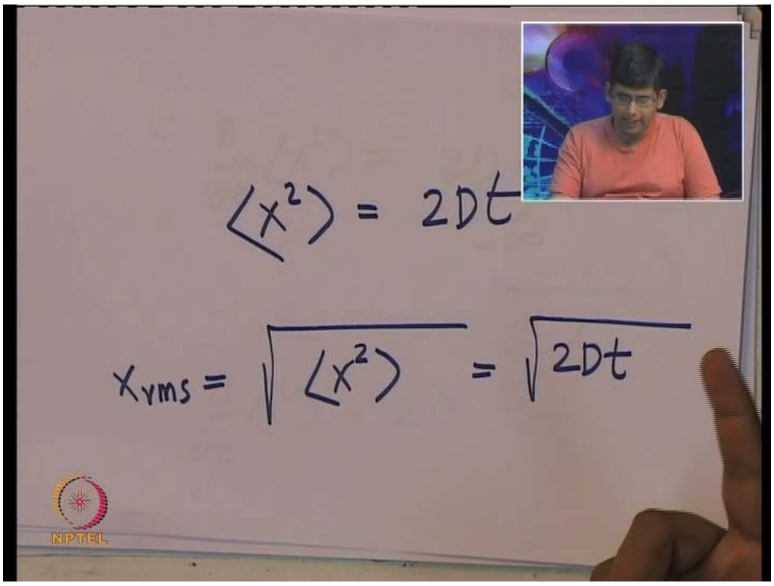

So, what did we get, we get x square average is 2 D t, we can say X rms is square root of x square average is square root of 2 D t. What is that tell you, what is this tell you, so this has lot of significance, so let us think about for a minute about the significant of this result.

So, look at here this once more is the result, look at this X square average is 2 D t, what is the X square average means; the rms or on the rms distance means the average distance that this would go to either side that is a rms distance this molecule will diffuse in a time t is X rms. So, what is this mean, if you wait for 100 seconds, so let say so let D is a constant t is time.

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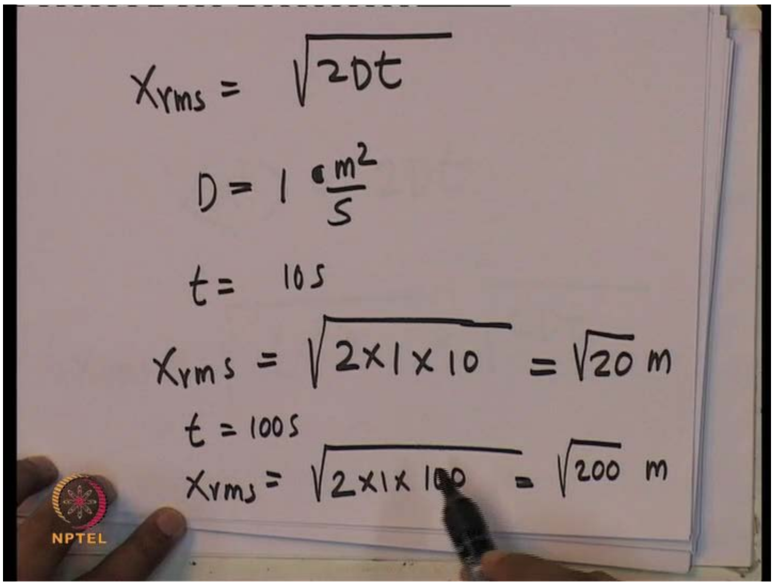

So, let us let we know that let us take for example, let us take for example, so let us take this X rms is equal to root of 2Dt is a very famous relation now let us see what is it. Let us take D is equal to, so what is the unit of D here, D will have a unit which is; let us take D is 1, let say is meters square per second, this will have a unit of meter square per second. Diffusion, coefficient as a mean it of meter square per second we will come into this, you will we will see how this is coming. But for the moment, let us take D has some number which is 1 meter square per second given to you.

Now the question is, let us say even t is equal to 10 second, how for this would have diffused; so X rms is equal to root of 2 into diffusion is 1 in to 10, so this is diffused a distance of root 20 meter, root 20 meter. Now, let us say after 100 seconds when t is equal to 100 seconds, how much these are diffused, when you take t equal to 100 second what you get X rms is equal to root of 2 into D is 1 itself this is 100 (Refer Slide Time: 45.01).

So, you know this is 200, so what is this, this is square root of 2 into 100. So, 100 square root of 100 is 10, so this is essentially what we get root of 200 meter, so this is root of 20 and this is root of 200, so now we can write root of 200 has 10 into root 2; so this you can write root 10 into root 2 and this is 10 into root 2 (Refer Slide Time: 46.15). So, these in this particular way, we can calculate how much distance it will travel in time t; if it is 100 seconds instead of gone, so you know root of 20, what is the root of 20? So, this is like root of 16 is 4 root of 25 is 5, so root of 20 is somewhere in between 4 and 5.

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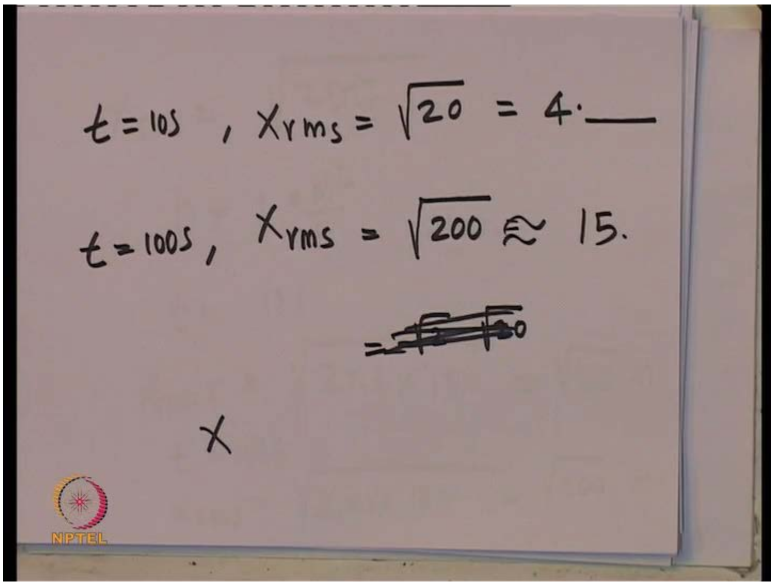

So, let us look at here, so first case, first when t is equal to 10 second we get X rms is equal to root of 20, we know that this as to be 4 point something, because root of 25 is 5 root of 16 is 4, so this is 4 point something calculate it yourself, what is root 20 and what is in 100 seconds that is, the time change by 10 times, if you wait 10 times longer it would have diffused a distance root of 200; what is the root of 100, root of 100 is root of 100 is 10, so root of 100 is 10. So, this is little about 10, so root of 15, so this is this is some quantity much larger than that; so this is basically what you get, you can write it as root of 200, can be written as root of 2 into root of sorry this is wrong, so what will be this number, this number will be like something between a very close to 15, because we know that root of 220 is root of 200 is, so this is something close to 15. So, this is some number which is very little less than 15, so calculate this number yourself, so even though the time increases 10 times here.

It did not travel 10 times it only traveled much less than 10 times. So, this what essentially it says, even though the time increases by 10 times, the distance traveled will be much less than 10 times.

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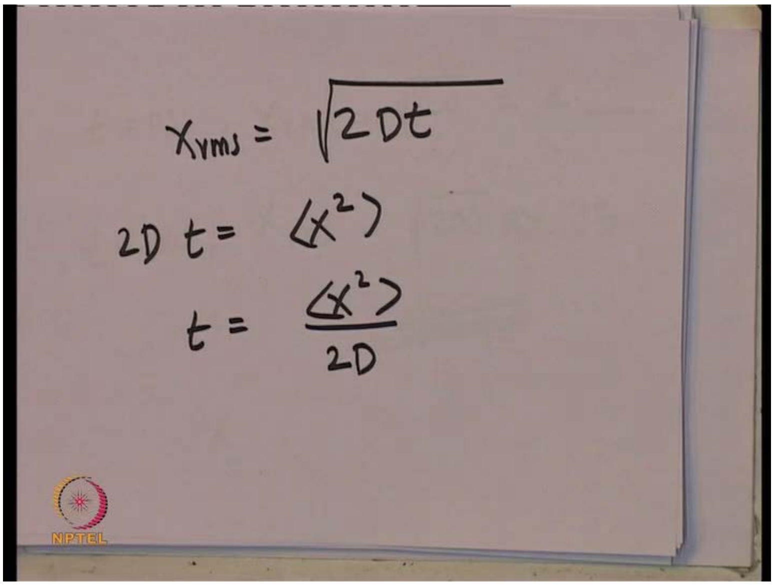

So, now let us take another example, let us take, so what we have is X rms is equal to root of 2 D t.

And let us now calculate, let us ask the w question, so let us do in another way let us at t is equal to x square average. So, what we had, 2 D t is X square average. So, let say t is equal X square average by 2 D. So, now let us ask the question, if we can here, as the question again, do it yourself ask this question if you want something to diffuse; let say if it is diffuse one micron let us take the example of some more protein molecule let say action molecules. And ask the question, what is the time it takes to diffuse one micron? and ask the question, how fast how long it will take, how much stay how long it will take to diffuse twice the distance just two microns. So, such kind of things can be calculated from what we learned so far.

So, just like what we did now, we can also calculate x average, which we will discuss later, but this is a very important relation which we use many different places, many different occasions, both in Biology, Chemistry, Physics, Chemical Engineering any field you take pretty much.

This relation is used, that is the X square average is 2 D t if and this is a very important consequence. And anything that will diffuse if you wait 10 times longer, it will not go 10 times further, it will only go much less than the 10 times much less than 10 times, so that is the whole message.

We just saw that if you, we just saw that if you wait 10 times more time the distance that will be travel will be much less than the 10 times. So, essentially what it to summarize the lecture what we learnt today is very important relation.

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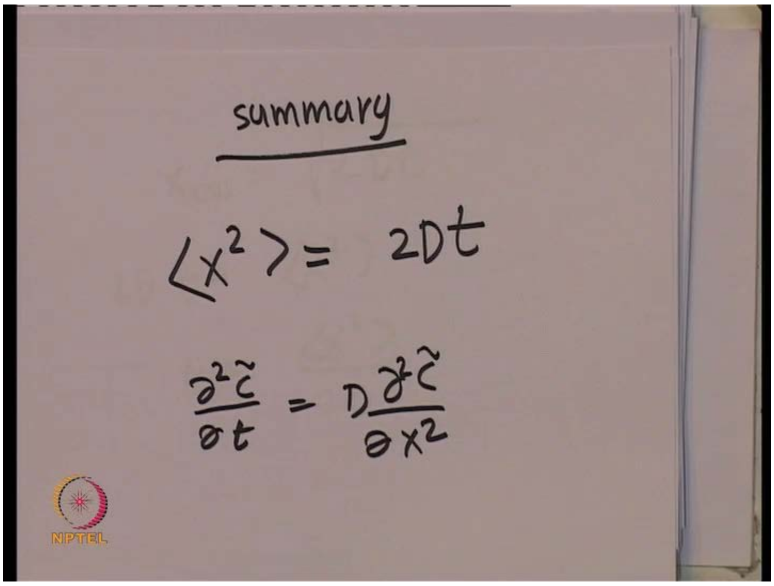

So, this is our summary just one equation X square average is 2 D t. So, this is our summary for today, because this is very important relation in Biology, in Physics. If you have learn spectroscopy and or any many different areas you might you might come across this relation.

So, just realize that without solving the diffusion equation, we started from this equation, without solving this equation by doing a trick by just realizing that the yet infinities, the concentration will be 0, we found that X square average is 2 D t.

So, with this important relation we will stop today’s lecture, we will continue little more about diffusion in the coming lecture very and there is another important relation we will discuss that in the next lecture. So, for this lecture this lecture let us stop it here now, bye.