Bio-Physical Chemistry
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Lecture - 10
Dipole-Dipole Interaction

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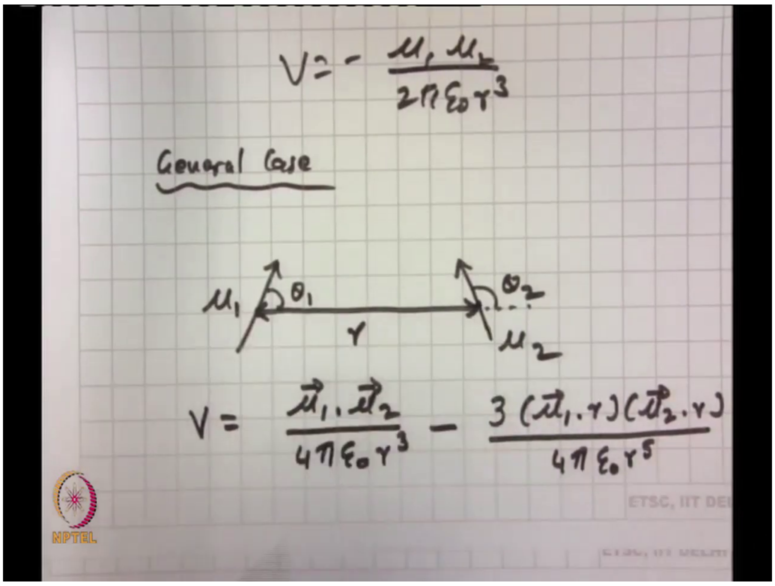

So, in today's class will go on with our interactions with regards to Dipole Dipole alright and in the last class what we actually derived was this expression where. So, V is equal to mu 1, mu 2, by 2 pi epsilon 0 r cubed right where these are the respective dipole moments of the interacting dipoles. Let us take a very general case. What I mean by general case is, the dipoles can be oriented with orientated with respect to each other at specific angles. So, what I mean by that?

For example, I have a dipole moment mu 1 in this case right and I have another dipole moment say mu 2, now this is if I take it from the center of these two dipoles let this be the distance between the two centers which is r. So, you can understand what is going to happen.

With respect to the distance between the two dipoles these dipoles are not parallel right. So, they are maintained at a certain angle. Say, this is angle theta 1 which mu 1 makes with this radius vector and if you look at this dipole, then this mix with this one an angle theta 2 ok.

So, this is the very general case now, we do not know what the angle it is we just trying to derive it for two dipoles oriented at certain angles. So, here we will not look at the derivation, but we will just write down the actual form.

The actual form is or the potential energy is can be written as V is equal to mu 1 dot mu 2 by 4 pi epsilon 0 r cubed that is the first term minus. Now this remember there is a dot product mu 1 dot mu 2; that means, we are talking about vector quantities now right minus 3 mu 1 dot r times mu 2 dot r over 4 pi epsilon 0 r to the power 5 ok.

So, this interaction energy can be derived and we will not go into the derivation. I can keep in mind the term on the right hand side we can see mu 1 dot r mu 2 dot r and we have r 2 the power 5 term at the bottom ok. These are essentially your dot products of a dipole moments with respect to the radius vector r which is the distance in between mu 1 and mu 2.

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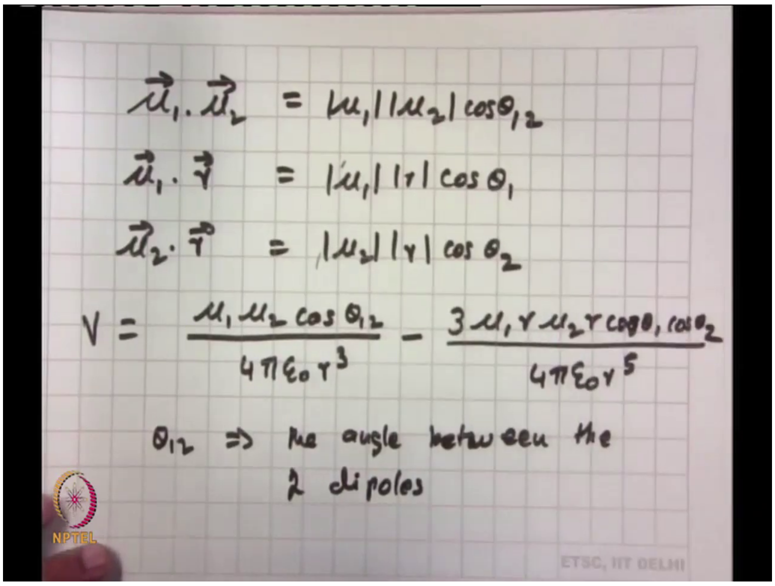

Now you know this definitely there I can write mu 1 dot mu 2 now these are the vectors I am talking about is equal to what? Mu 1 right mu 2 then the angle between the two dipoles right. So, I can write cosine of theta 1 2 that means, this is the angle between the two dipoles and remember this when I am writing this like mu 1 and mu 2 these are absolute magnitudes I am talking about So, now these are scalar quantities.

Similarly, if I can write mu 1 dot r what should I be writing? I should be writing mu 1 r then cosine of theta 1 right. So, all these again are vector quantities please remember and if I am writing mu 2 dot r then this is equal to mu 2 r cosine of theta 2. So, again these are your absolute magnitudes. So, from now on ward what I will do is, I will not represent them like this form I will just write mu 2 r and all these things straightaway.

See if I am having this and if I am put this back, if I am putting this back into my original expression then I have V is equal to you can write mu 1 mu 2 cosine of theta 1 2 over 4 pi epsilon 0 r cubed and the next term then becomes 3 mu 1, r mu 2, r cosine of theta 1, cosine of theta 2 over 4 pi epsilon 0 r to the power 5

So, again I will just plugged in these dot products right this theta 1 2 is what? Theta 1 2 is the angle between the two dipoles now please keep that in mind. So, theta 1 2 is the angle between the two dipoles and obviously, theta 1 and theta 2 are the angles that these dipoles make individual with respect to the.

Student: Separating them.

r which is separating them the distance and just there is an over writing here. So, this is essentially cosine of theta 1 and cosine of theta 2 ok. Now this thing can be further simplified as you can see. So, this remains like this you can see throughout you have a mu 1 by mu 2, mu 1 times mu 2 4 pi epsilon 0 term common I can take out and not only that you see now you what you have out here? You have r and r which is essentially what? r squared you have r to the power 5 term here.

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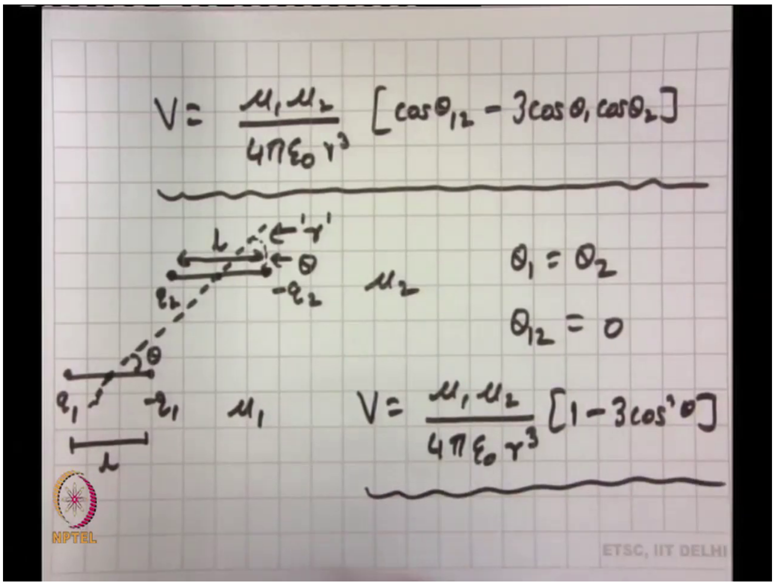

So, what I can write this one as further simplification. So, V is equal to mu 1, mu 2 by 4 pi epsilon 0 r cubed then what should I be writing here? Cosine of theta 1 2 minus.

Student: (Refer Time: 06:50).

3 cosine of theta 1 times cosine of theta 2 right. So, this is the most general expression you can have for two interacting dipoles making you know certain angles theta 1 2, theta 1 and theta 2 respectively the definitions as we have discussed. Now let us take a very specific case let us take a very specific case.

For example, let us take a case where I have two dipoles like this these are two dipoles right. So, I can have this one as say q 1 minus q 1 and this is.

Student: q 2.

q 2.

Student: Minus q 2.

Minus q 2 and you can understand. So, this dipole has its orientation such that the positive end is closed to the negative end of the other dipole right. So, this is your mu 1 and this is your.

Student: Mu 2.

Mu 2 again the length is given as.

Student: (Refer Time: 07:57).

l same for here the length is given as l. Now remember what distance we were talking about. So, this distance is again from the mid point of the dipole. So, if I can extend if I can extend my r. So, this is your r right. So, this one makes an angle theta and this one if you can understand this one also makes an angle theta do you get that?

So, this one makes an angle theta; that means, mu 1 makes an angle theta with the radius vector r or the distance vector r and this one also makes an angle theta; that means, theta 1 is equal to theta 2. So, here I can say theta 1 is equal to theta 2 that is one. Now, tell me what happens to theta 1 2 theta 1 2?

Student: 0 (Refer Time: 08:51).

0. So, theta 1 2 is 0 now and if you put these; if you put these here what are you going to get?

Student: 1 minus 3.

That means, I can get now I can simplify my V further by writing as V is equal to mu 1 mu 2 4 pi epsilon 0 r cubed right then what is my first term? Cos 0 is 1 minus 3.

Student: 3 cos.

Cosine square of.

Student: (Refer Time: 09:21).

Theta. Have you ever seen an expression like this before? Where we seen?

Student: (Refer Time: 09:32).

But anyway this is one of the places you can seen the expression and this expression also comes in a very important feature in fluorescence spectroscope which is called faster resonance energy transfer. There also we talk about you know interacting dipoles which are point charges and there this orientation also comes in ok.

But again keeping this orientation in mind right where theta 1 and theta is theta 1 and theta 2 equal these are parallel, theta 1 2 is equal to 0 you have this ok. Now this is an expression guys you will have to remember. The base expression which is the one we started with.

This base expression; that means, the expression we want to started with this you do not have to remember at least I will provide this with you in the exam ok, but any further simplifications based on this expression, you will be able to you will have to be able to do that now what do I mean by that? Let us take another case now.

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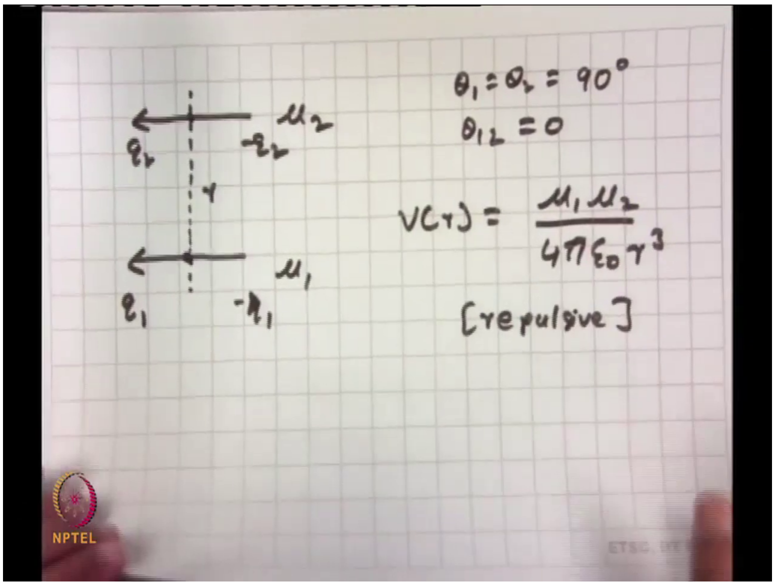

So, just simplifying this further we can take another case, where we can have the dipoles like this right. I can have the dipoles like this. So, this is say mu 1, this is mu 2 again r is from the center right you can have this it does not matter what it is and this is your r this is your r. Now tell me what is theta 1 equal to theta 2 here?

Student: 90 degrees.

90 degrees ok. What is theta 1 2? Same again parallel 0 now. So, what does V of r become now? Let us look at this expression.

Student: (Refer Time: 11:45).

3 cosine of theta 1 cosine of theta 2 what is cos 90?

Student: 0.

0 this is also 0. So, this term cancels out I mean this term goes away what is this?

Student: 1.

1 good now.

Student: (Refer Time: 11:58).

Now, think about this, now think about this I just be careful about the sign now. You see these are like charges right I can have q 1 minus q 1 right. I can have q 2 minus q 2 because I a m keeping the convention of this sign of the dipole moment where what direction dipole moment will be going. So, if that is the case what should the sign V should this be attractive or repulsive you tell me?

Student: Repulsive.

It should be repulsive yeah it should be repulsive right because you see q 2 is close to q 1 which are both positively charged ions and then q 2 is close to q 1 which are again negative charge the negative ones. So, this one would be mu 1, mu 2 times over 4 pi epsilon 0 r cubed and the interaction is repulsive in nature because your like charges are just on top of each other.

So, think about the different orientations you can have now think about the different orientations you can have. So, I can take some other orientation examples right. So, one of the other orientation is this one this flips to give you a very stable interaction potential, when this one reflect; that means, minus q 2 would come here and this plus q 2 would go there what would you get? You would be getting a.

Student: Minus.

Same thing with a negative sign because it is a.

Student: Attractive.

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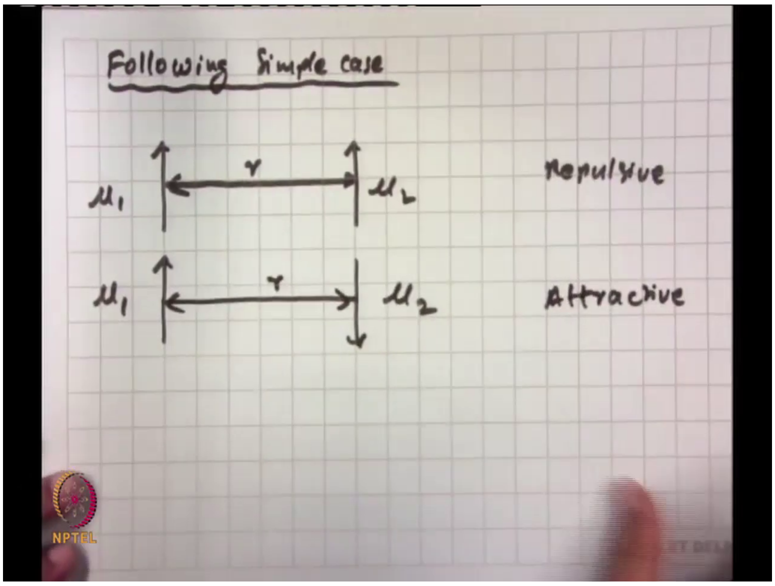

Attractive potential it is an attractive potential that is why. So, you know based on this I can have the following I can have the following simple cases. So, what are the cases? I can have 2 dipole moments aligned like this right what we just saw. So, this is mu 1, this is mu 2 and this is again r.

So, this we saw is what repulsive right you can see both are pointing in the same direction. The next one I can have is something like this mu 1, mu 2 again separated by distance r this is attractive ok. I can have another orientation like this which is I have something like this which is one dipole mu 1 right.

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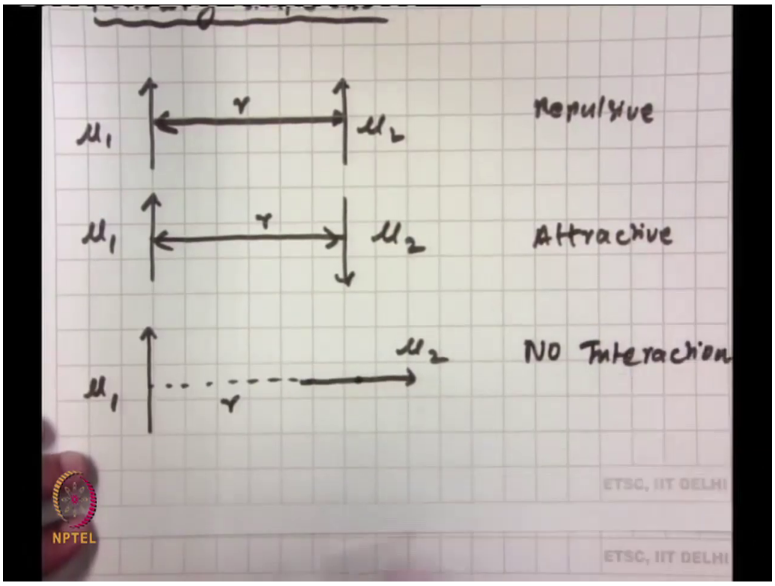

And then I have another dipole which is like this, this is mu 2 and again. So, distance to the centre is r. Now, here you have to tell me would this be attractive would this be repulsive?

Student: (Refer Time: 14:44).

My answer is and this you have to figure it yourself there would be no interaction.

Student: (Refer Time: 14:54).

You understand why right there would be no interaction what is theta 1 2 here?

Student: (Refer Time: 15:05) 90.

What is theta 1 2 here?

Student: (Refer Time: 15:07).

It is not 0 its 90 degrees right.

Student: 90 degrees.

Because you extended like this its 90 degrees. So, what is cosine of 90?

Student: 0.

0 and then you can figure out how it comes out right. So, I have already given a hint these things in the exam you should be able to figure out by yourself and write down the respective interactions right.

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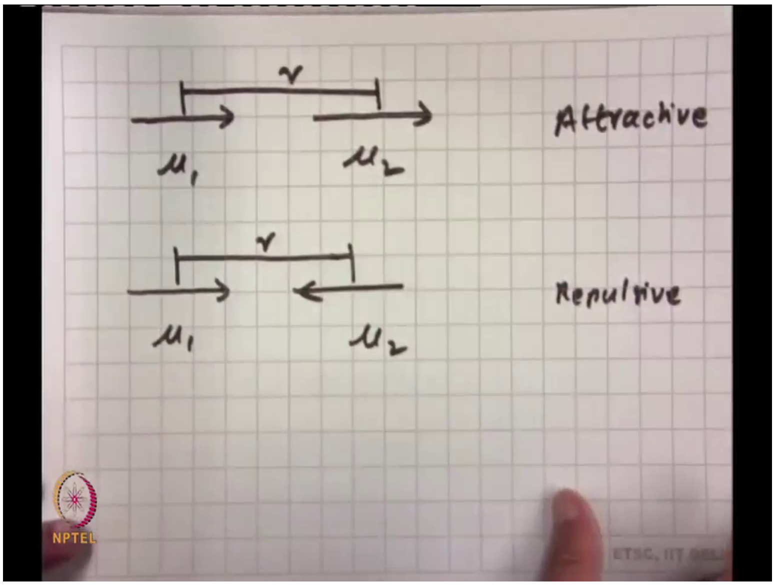

So, what are the two other simple cases we can have? So, continuing with our cases we can have two dipoles like this right. So, this is mu 1 this is mu 2. So, would this be attractive or repulsive this would be?

Student: (Refer Time: 15:45).

Attractive right.

Student: Yes.

Or I can have this one this one again mu 1 mu 2. So, r is essentially from the middle this is r again here this is r. So, this would be repulsive ok.

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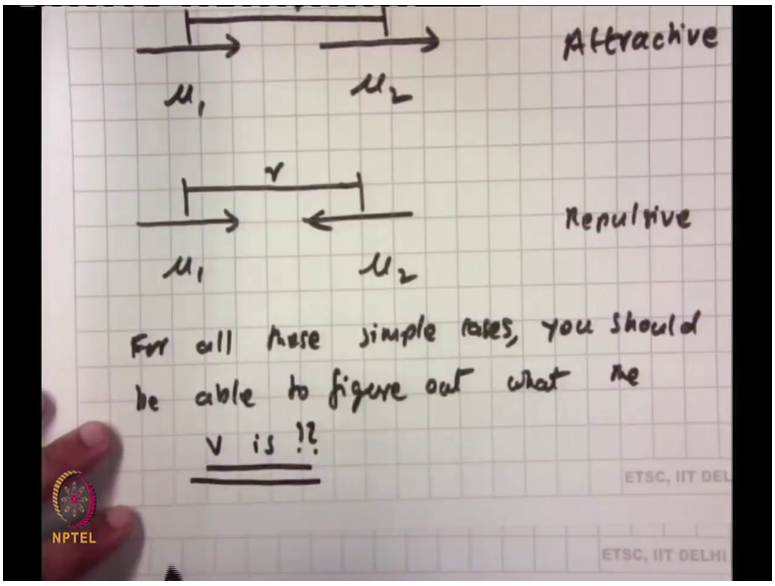

So, the bottom line is for all these simple cases you should be able to figure out what the interaction potential V is ok. This you should be able to figure out. So, let us move on now.

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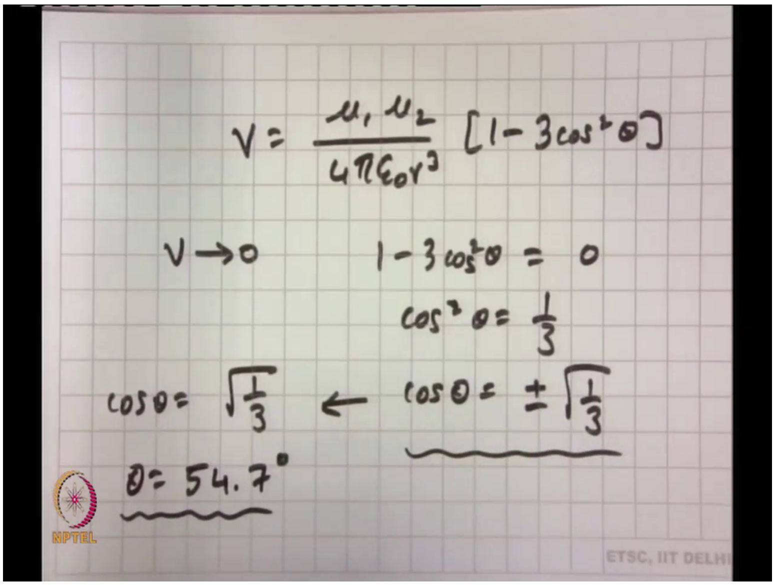

Consider the situation where V is equal to mu 1 mu 2 which we just derived 4 pi epsilon 0 r cubed 1 minus 3 cos square theta or cosine square theta. Now, just looking at this under what conditions can V or a V tends to 0? What can I say about this? Can you tell me any factor I can say tends to 0?

Student: (Refer Time: 17:28) can be 0. (Refer Time: 17:30).

1 minus. So, see mu 1 and mu 2 cannot be 0 right because we know they have dipoles that was given if mu 1 is 0 then obviously, we are not going to talk about anything else. So, when it is.

So, this one; that means, 1 minus 3 cosine square theta should go to 0 so; that means, what you are trying to find out is at what angle; that means, at what angle you would not be having any interactions between the dipoles that essentially what you are saying right; that means, if V is going to 0. So, here I can write cosine square theta is equal to 1 by 3 or cos of theta is equal to plus minus 1 by 3.

Now, based on this if cosine of theta is equal to root 1 by 3 then theta comes out to be 54.7 degrees ok. See in some sense this will come back to later in the course when we talk about florescence, but in some sense you can realize one thing. If we have two dipoles which are orientated at this angle, its essentially a magic angle right; that means, it do not have any interactions. So, there are how can how does the potential picture look like? What I mean is suppose I have a dipole like this.

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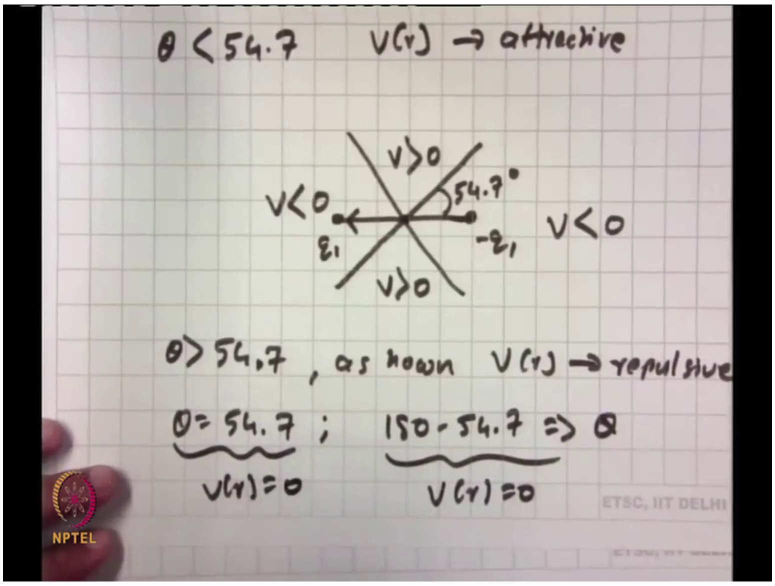

Again let me start from centre of the page, I have a dipole like this right and I am trying to find out regions where they are attractive and repulsive in terms of your V.

So, let this be the centre and these are two lines, I am drawing these are two lines I am drawing ok. Now this angle is 54.7 degrees and say this is your dipole this is q 1, this is minus q 1. So, you can understand one thing, if theta the theta you are talking about if theta is less than 54.7; that means, if theta.

So, in this region in this region from here to here your V actually is less than 0 in this region your V is less than 0 why? Because 54.7 is very interaction is 0 right when you start from here your interaction was attractive. You move like this, you move like this, you move like this, you go to 0 then beyond that you will go into the repulsive regime.

So, between these two crosses or between these two lines, I can say this is V is greater than 0 right similarly here V is greater than 0 and then again you come on to the other side, you have V which is less than 0 ok.

So, these are very nice picture which tells you how the dipoles if they are oriented, what you know they are respective nature of attractions or repulsions would be nature of potential energy would be whether attractive or repulsive?

Now to explain it; that means, if theta less than 54.7 then V of r or V essential is attractive right. If theta is greater than 54.7 is greater than 54.7 as shown V of r because it depends upon r is repulsive is repulsive and what about the angles at which you will be not having any interaction?

Student: Equal.

So, one is theta is equal to 54.7 what is the other angle?

Student: 180 minus.

180 minus this right 180 minus this. So, the other one is at 180 minus 54.7 at 180 minus 54.7 right this is another case where if this is your theta here again V of r is equal to 0 like V of r is

equal to 0. So, essentially this line and this line are what? Your lines of 0 interaction that you can understand now right this line and this line essentially the lines of 0 interaction.

So, what it means is now start looking here, if I have; if I have say a charge which is say plus q 2 here right now q 2 is close to minus q 1. So obviously, if you are in this regime, this q 2 is closer to its opposite charge hence; obviously, your interaction is attractive.

Now, the moment you come here in the middle what happens? This was the 0 line by the moment you come here you are coming slowly closer to what q 1, now these are like charges hence your repulsive interaction comes in. So, that is how you can think about it. So, this was about you know the; you know the regions of your attractive and repulsive interactions and also please keep in mind the different alignments you can have.

So, if you would know that formula then based on theta 1 2, theta 1 and theta 2 you should be able to drive your interaction potential you know that you should be able to do. And the significance is if anyone gives you a system like that and because you would know V of r for any given angle you would be easily able to calculate because you know V of r right ok.

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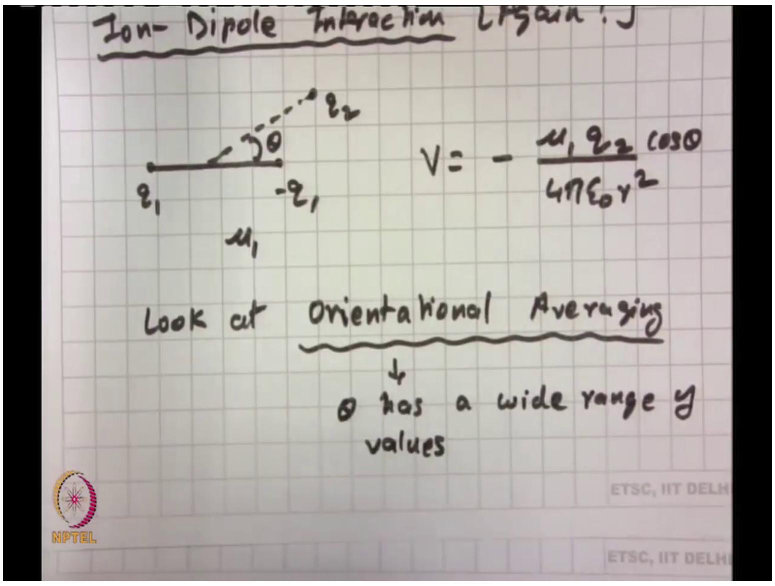

Now, moving one step further let us think about this. We will go back to an ion dipole interaction and I will tell you why. You are looking at it again yeah the reason is this.

See when we if we were remember we had a dipole like this right say q 1 minus q 1 right this was l the length of the dipole and we had a charge out here say q 2 which was making a certain angle theta right and for this one what was the V? Do you remember it was. So, if this is the dipole moment of mu 1 then it is minus mu 1 times q 2 right then we had a factor cosine of theta, then we had 4 pi epsilon 0.

Student: r square.

r square and this is again squared because we are talking about a dipole interacting with an ion or vice versa, but think about real life situation. If you have a freely tumbling dipole, would you be would you be maintaining a single theta? You will not be maintaining a single theta what you would instead be maintaining is a range of theta values a range of theta values.

So, what I am what we are going to do now is we are going to look at we are going to look at something known as orientational averaging. We are going to look at orientational averaging; that means, theta has a wide range of values and I will just tell you what the range is, tell you what the range is. So, this what are you going to look at and you will be surprised what this orientational averaging can what this orientational averaging can do interaction just wait for this.

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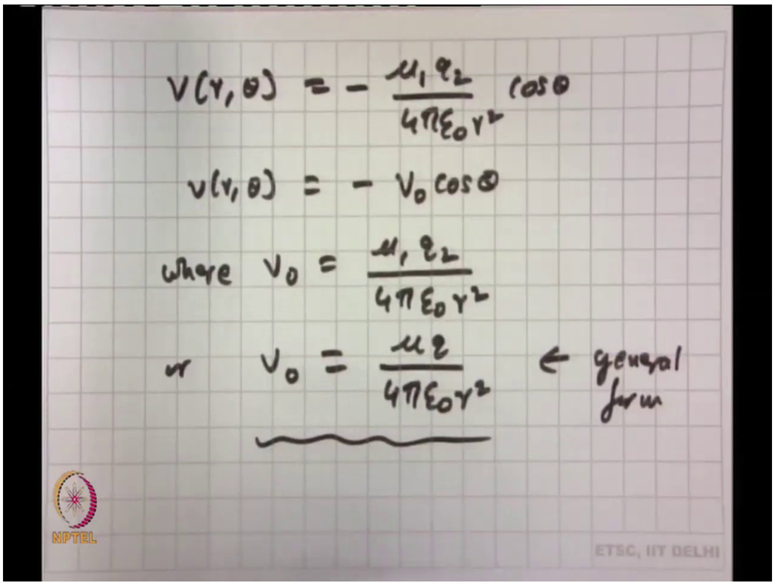

So, look at this equation again and let me write this equation again just to make the connection. I can write the previous equation as V of r theta because it depends upon theta it also depends upon r to be equal to minus q mu 1 q 2 4 pi epsilon 0 r squared cosine of theta and this.

I can simplify further by writing V of r theta is equal to minus V 0 times cosine of theta, where see V 0 is equal to where V 0 is equal to mu 1 q 2 by 4 pi epsilon 0 r square or for a general case I can write or for a general case I can just write mu I will remove the subscript 1 and 2 q by 4 pi epsilon 0 r square right this is a very general form right.

So, remember out here since we are involved in only the angular orientational averaging our radial part does not come in. So, it essentially comes into the constant V naught because we are doing an orientational averaging with respect to theta now what do you mean by that? To find this; to find this orientational averaging; that means, the potential coming from orientational averaging we will solve an integral like this we will solve V of r we will solve V of r.

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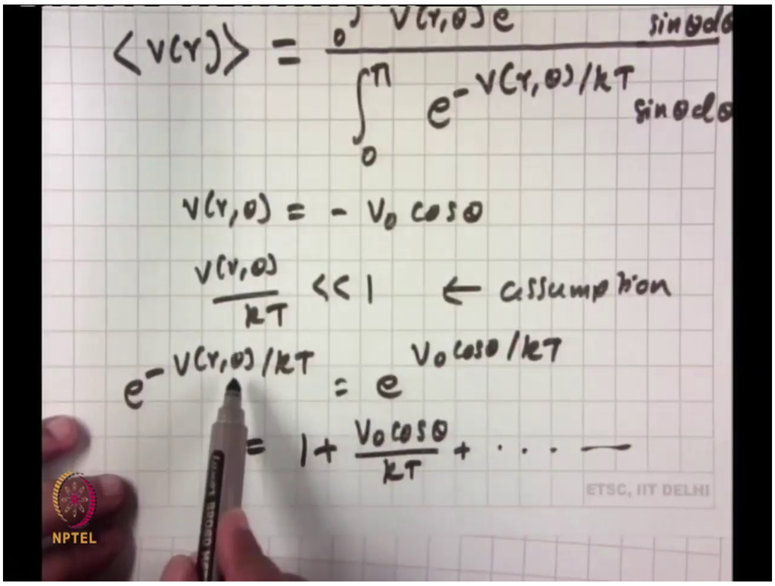

See I am not writing r theta anymore the reason is because I am doing an orientational averaging I am essentially integrating theta out right there is no longer any theta dependence that is what I am doing.

So, this is equal to now this you have to remember ok. Let us look at the limits 0 to pi 0 to pi V of r theta e to the power minus V r theta over k T then you would be having sin theta d theta and in the denominator you have this minus V of r theta k T sin theta d theta. So, again.

So, this is your average V of r. So, this its like your expectation value this is your average value V of r is equal to the numerator is V of r theta which you know e to the power minus V this is r its not V, its looking like V its r theta by k T over e to the power minus V of r theta by k T sin theta d theta right. So, this is your integration you know that is integration variable.

Now, look at what theta varies theta varies from what? 0 to pi. So, you can think about a dipole and an ion. So, dipole can see this is the angle theta, then the charge can go from here to here if you go the other way you just essentially repeating that is what you are doing, but the charge can go from here right any theta theta theta theta and it can go to the other side right covering an angle of pi which is 90 degrees.

So, this is what we will have to solve guys and actually we are going to do that right we are going to do that. So, how? We will make an approximation first of all we know that V of r theta is equal to what? Minus V 0 cosine of theta we know from before right. We will also do one thing we will see V of r theta by k T is much less than 1 is much less than 1 right.

Do you understand the significance of k T here? You can realize this term has a temperature dependence; that means, these forces would be dependent upon on your thermal energy and here thermal energy is reflected by what? The k T term or r t whichever way you want to look at.

So, based on these two and specially this is an assumption we are making specially this is an assumption we are making say if V of r theta by k T is much less than 1 is much less than 1, then what I can write is look at e to the power minus V of r theta over k T.

So, what is this equal to? This is equal to I can write e to the power V 0 cosine of theta over k T right because V of r theta is equal to minus V 0 cosine of theta and I already had a negative sign here and I know this one is much less than k T. So, what I do is, I do an expansion of this Taylor expansion of e to the power x if I do a Taylor expansion e to the power x what do I get? I get 1 plus V 0 cosine of theta over k T and so on right.

So, I am making this assumption and based on this assumption, I am simplifying my problem or we are simplifying our problem by expanding this in terms of the Taylor series expansion and just we take the first two terms. 1 plus V 0 cosine of theta by k T. So, this is something you know by this term you are familiar right with did it for the ion dipole too remember 1 plus l by r over 1 minus l by r and we do not consider the other terms essentially the same thing we are doing. So, take this and put it back in the integral ok, but what we will do is now, we will look at the numerator and denominator separately right.

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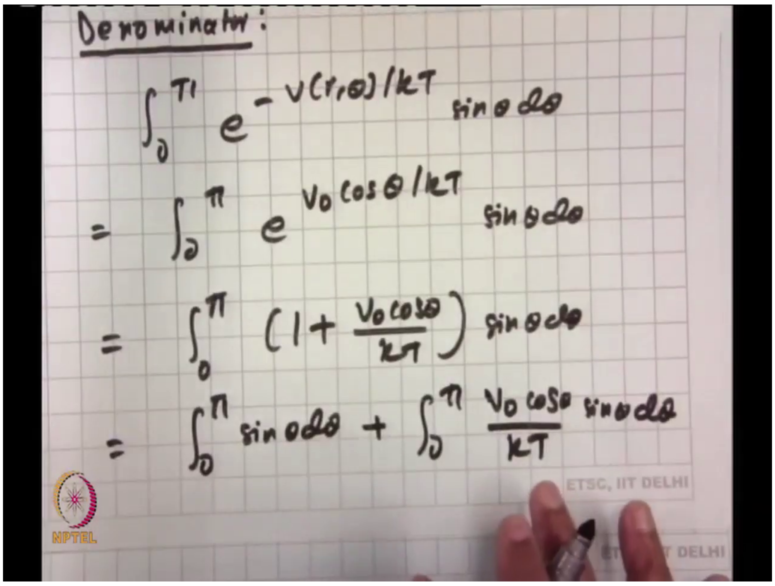

So, let us look at the denominator. So, let us look at the denominator of your integral. So, the denominator is 0 to pi again I am writing, e to the power minus V r theta by k T sin theta d theta ok.

So, this is essentially again 0 to pi e to the power V 0 cosine of theta over k T sin theta and d theta and using the assumption; using the assumption which we have already done in the previous sheet we can write this 0 to pi 1 plus what? V 0 cosine of theta over k T right times sin theta d theta. And this I can further simplify as 0 to pi I can write what is the first term? Sin theta d of theta plus 0 to pi V 0 cosine of theta k T then I can write sin theta d theta.

So, you can see what we done is for complicated exponential integral, we have split it into 2 very easy to do sum of integrals ok. So, let us take these two integrals (Refer Time: 33:21) 1 this one and this one. So, 0 to pi sin theta d theta is equal to what?

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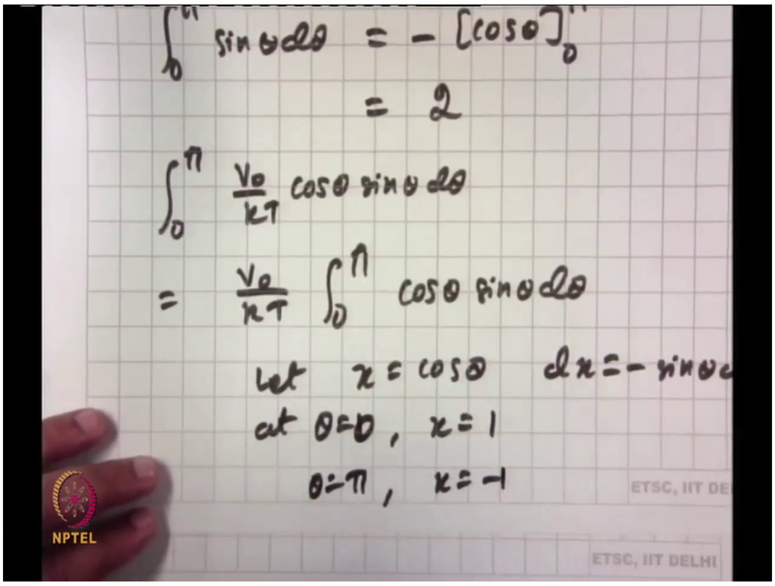

Student: Minus cos theta.

Minus cos theta in the range 0 to pi now tell me what the value is thank you. So, the value is 2 does everybody realize that?

Student: Yes.

This is cosine of pi minus cosine of 0 minus 1 minus 1 plus 2 great. Now this was the easy one right let us look at the other one, the other one is also very easy. See the other one I am looking at 0 to pi V 0 by k T cosine of theta sin theta d theta. V 0 by k T is a constant right because we are integrating over theta right.

So, though V 0 has the term r it does not matter to us because we are not even integrating over d of r, we are doing an angular orientation averaging right. So, r essential is a constant. So, I can write it has V 0 by k T obviously, k T is also a constant, 0 to pi cosine of theta sin theta d of theta and let us do a trick I am sure you guys know.

Student: (Refer Time: 34:41).

Let x equal to I can do that or I will also do this [FL]. Let x is equal to cosine of theta right then what is d x equal to? What is d x equal to?

Student: (Refer Time: 35:00) minus (Refer Time: 35:03).

Minus.

Student: (Refer Time: 35:04).

Sin theta d theta ok. So, this one this integral ok. So, one more thing. If x is equal to cosine of theta at theta equal to 0 sorry theta equal to 0 because I have to change the limits of x what is x equal to? 1 right at theta is equal to pi what is x equal to?

Student: 1.

Minus 1 right, there are many ways of doing this integral. So, I am just showing one of the ways you can even do it has as I said, we can write; we can write this one as is been look for new page. So, we can write this one now as is equal to V 0 by k T right I have a negative sign coming here then what do I have?

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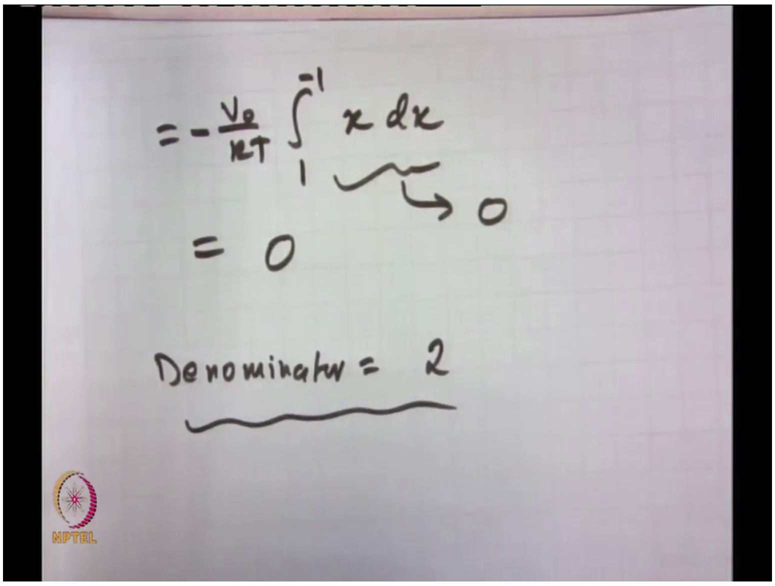

I have 1 to minus 1 I do x and look at this sin theta d theta what is sin theta d theta? This is essentially d of x right I already have d of x. So, I can put.

Student: dx.

d of x, now there is an extremely similar integral is not it and what is the value of this integral? What is x d x?

Student: x square by 2.

x square by 2 and then what will you get?

Student: 0.

0 good. So, this is 0. So, this one goes to 0 simple right. So, see a very intimidating integral which was down at the denominator gives what a value of 2 essentially. So, the denominator is equal to 2, the denominator is essentially equal to 2 right good. If you are done with the denominator what did we have in the numerator?

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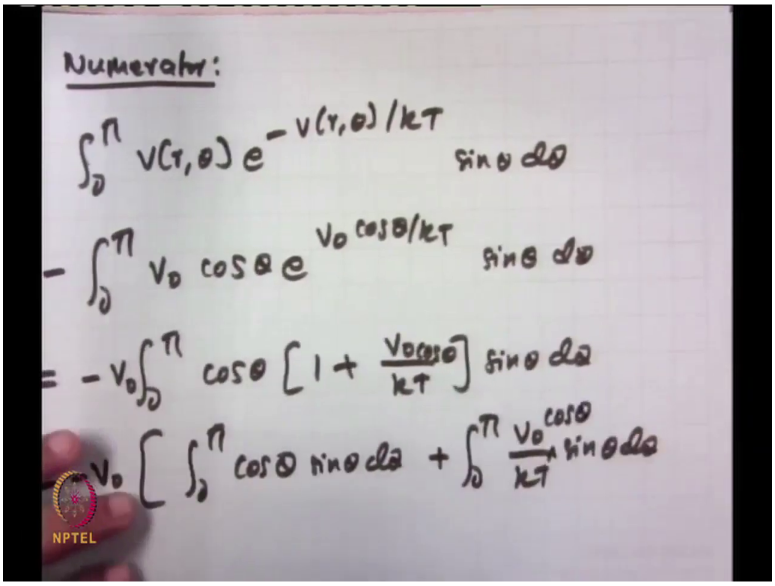

So, let us look at the numerator now. The numerator is 0 to pi V of r theta right e to the power minus V r theta by k T sin theta d theta right that is what we have for the numerator.

Now, this what was V r theta? I can write this as 1 as 0 to pi V r theta was minus V 0 cosine of theta. So, I can take the negative out sign out here and I do V 0 cosine of theta e to the power what should I write here? I can write V 0 cosine of theta over k T sin theta d theta ok.

Going step by step. Now this is equal to guys this is equal to minus 0 to pi I can keep the V 0 outside I have cosine of theta, but this one is already simplified form is not it? 1 plus V 0 over k T, then sin theta d theta and I do a further simplification I can write it has minus V 0, then open large brackets here is 0 to pi cosine of theta sin theta d theta right plus 0 to pi V 0 by k T sin theta d of theta.

I missed one is not it what did I missed did I miss anything? Just check ok. So, what I missed in this case is, I missed in this case is cosine of theta ok. Now these are the two integrals we have to solve essentially these are the two integrals we have to solve. If you are going to solve these two integrals what are you going to get?

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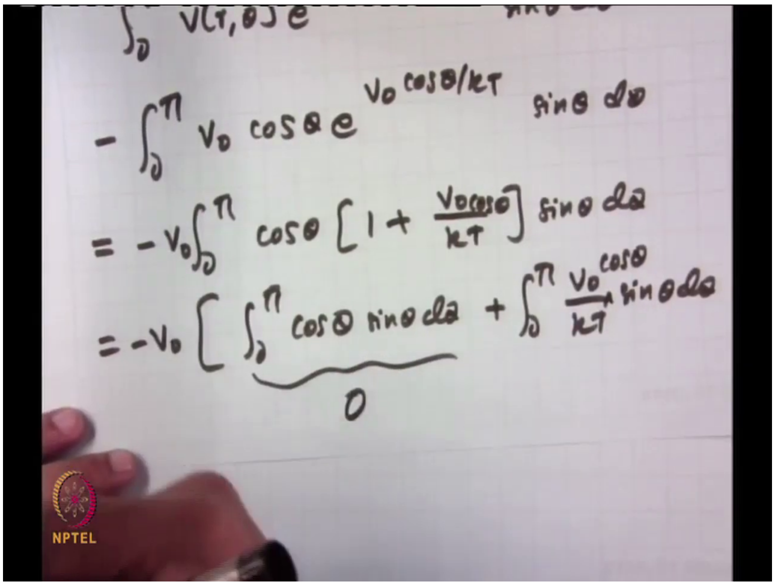

So, for the first one what is it? The first one is 0 we already know we did previously. So, the first one is already going to 0.

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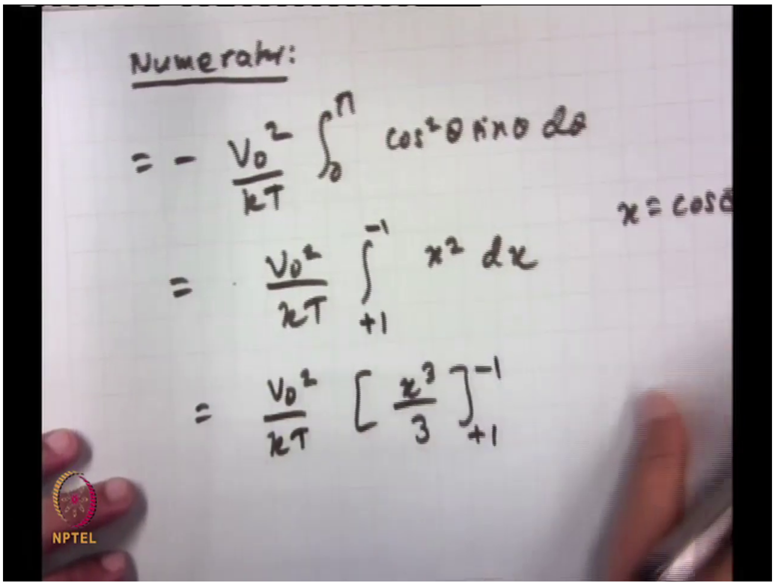

So, then for the numerator; for the numerator we left with. So, the numerator again we left with is equal to my minus I can write V 0 squared because I have a V 0 out here I can write V 0 squared, then what I am what am I solving now?

Student: (Refer Time: 39:39).

Right, but if you go back to this again actually I missed another term.

Student: (Refer Time: 39:46) cos (Refer Time: 39:47).

I meet I missed a cos theta. So, I can just write cosine square theta here otherwise it will also go to 0 if you do not want, yeah, so that is my mistake ok. So, coming again back from here.

So, minus V 0 square then I have 0 to pi cosine square theta, sin theta d theta by k T. How do I solve this one? I actually do the same principle again I allow cosine of theta to be x right and this would become what?

Student: (Refer Time: 40:23).

I can write V 0 squared over k of T right then I can write minus 1 sorry.

Student: (Refer Time: 40:33).

Plus 1 to minus 1.

Student: x square.

x square then d of x again putting x is equal to cosine of theta right. See we are a negative out here right and this is negative is cancel from here because of this. What do we get from here? V 0 square by k T now I have its not x square by 2 anymore right what is it? x cube over 3 plus 1 minus 1.

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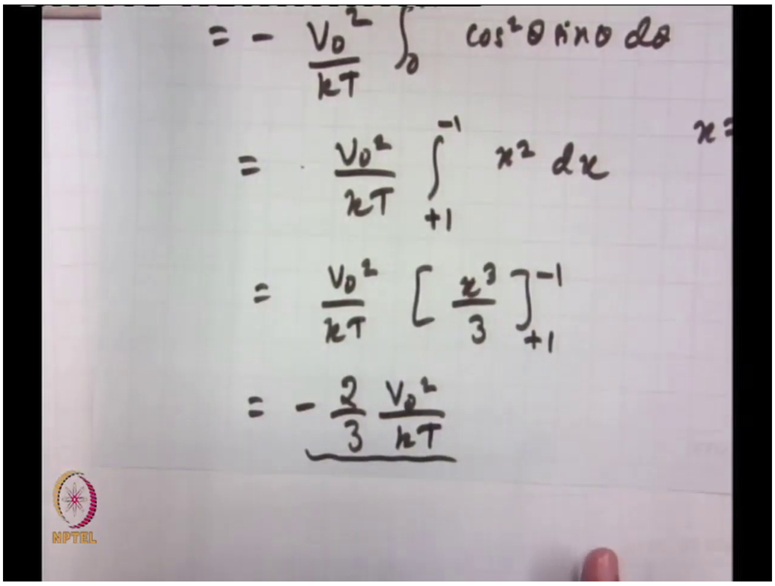

What I am going to get tell me? This is minus 1 by 3 minus 1 by 3 again anyway. So, I would be getting minus 2 by 3 V 0 squared over.

Student: k T.

k T ok. You should be feeling happy now see what you started from? You started from a very fearful integral right and what did you get the denominator was 2 and the numerator is minus 2 by 3 V 0 square over k T and no more V 0 as its a constant.

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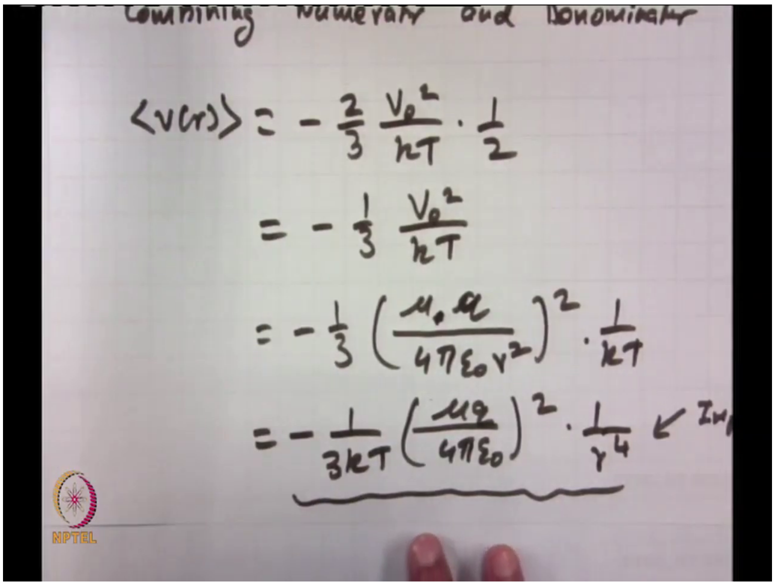

So, let me combine. So, combining numerator and denominator then average of V of r is equal to minus 2 by 3 V 0 squared over k T and what did I have in the denominator? 2. So, its essentially minus 1 by 3 V 0 squared over.

Student: k T.

k T what was V 0 equal to? So, I can write minus 1 by 3 then I can write mu 1 this is this one was q right I can just write mu q let us take out the subscript, I can just write mu q then what did I have in the bottom? 4 pi.

Student: Epsilon (Refer Time: 42:44).

Epsilon 0 r squared. So, this is essentially what? Whole squared over k T I am just plugging in V 0 right. You follow that right I am just plugging in V 0 look at this or you can further write this as minus 1 by 3 k T ok, then I can write mu q over 4 pi epsilon 0 squared what happens to r squared now? It goes to r to the power.

Student: 4.

4 it goes to r to the power 4 and this is important goes to r to the power 4 and this is extremely important. So, there two important aspects one is you can see this is V of r is going to depend upon t because obviously, your thermal energy is going to going to have an effect on your potential energy of interaction ok.

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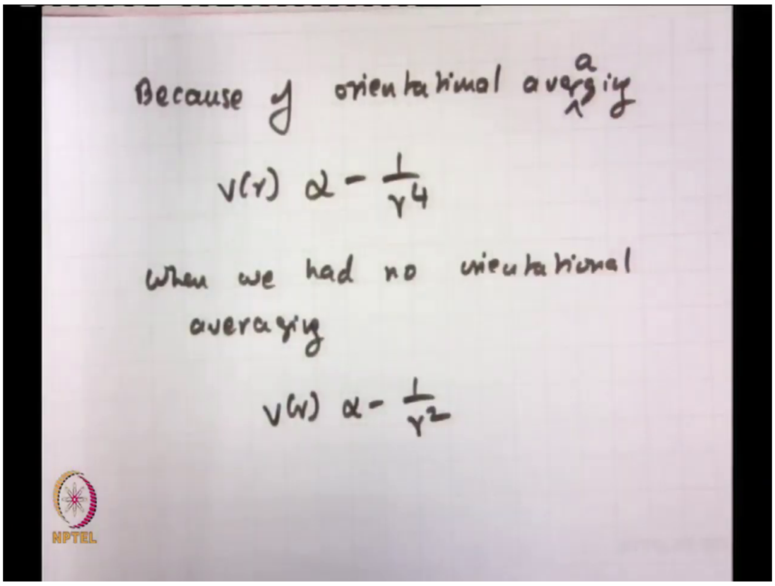

And the second point is because of orientational averaging because of orientational averaging, now V of r is proportional to minus 1 by r to the power 4. When we had no orientational averaging then V of r was proportional to what? Minus 1 by r squared minus 1 by r squared. So, again guys please understand the implification of this or the implication of this rather.

The implication is one your V of r definitely depends on the temperature because your temperature is too high, you are going to disrupt all potential energies of interaction right thermal energy is too high. Second is the moment you bring in orientational averaging you essentially just square this term which was initially obtained from a constituent value of theta ok.

Now those should be I will I probably this is you know where we are going to stop for the class today, but I mean let me tell you this, the one we derived for this dipole dipole interaction what was it? It was 1 by r cubed right for a fixed angle theta. So, you in that case also if you bring in this orientational averaging where will it go to?

Student: (Refer Time: 45:30).

It go to 1 by r to the power 6. Take this 1 by r to the power 6 and extend it to what you know in the case of Van der Waals interaction the attractive forces, what was the last term?

The last term was also r to the power 6 do you remember the attractive term? You have say a by r to the power 12minus b by r to the power 6 that also has an r to the power 6 and the Van der Waals forces are essentially what? Induced dipole dipole forces right and because you have induced dipole dipole see its still essentially dipole dipole and because you have an dipole dipole their attractive term is still r to the power 6.

So, hopefully, I have not put you off to much by the derivation, but you know in some cases the moment you do the derivation you have a much better feeling what actually what is going on, then just looking at the formula and that is why we did this rigorously and if any point of time you would have to do a derivation like this, you would be able to do it ok.

So, this derivation the last derivation you know you do not have to remember for the exam, I am not going to ask you this derivation, but what you should be remembering is the effect of this orientational averaging and for iron dipole dipole dipole what are the different dependencies on r ok. How the range changes from columbic r to r square to r cubed and then also r to the power 4 and r to the power 6 because of orientational averaging good.