

Vander Waals Force

Dr Manigandan S.

Department Chemical Engineering

Indian Institute of Technology, Ropar

Lecture-30

VDW force between two infinitely long blocks

Welcome back, so in today's video lecture uh in this video lecture we will look at the uh you know Vander Waals forces in detail ,okay ,uh so ,as you know, uh there are, uh, three types of forces within van der Waals forces ,we will look at them in detail ,okay and apart from that we will also look at how to calculate the pairwise interaction between the molecules and or between the macroscopic bodies which are made up of its own constituent molecules, right ,sometime you may have to do the pairwise interaction between flat surface as well as the curved surface or between two flat surfaces. So, by knowing the calculation part of the pairwise interaction between these two bodies, one can calculate for numerous cases. So, these are something we will look at in detail in this video. Let's begin.

(Time: 1:31 min)

The screenshot shows a video lecture slide with the following content:

- Van der Waals force** (Title)
- van der Waals forces** (Section Header)
- a. Induced dipole-induced dipole (London or dispersion)**
- b. Induced dipole-permanent dipole (Debye)** (Polar and non-polar molecules)
- c. Permanent-permanent dipole (Keesom)** (Due to Electronegativity)
- The van der Waals forces are always attractive.**
- It is relatively long-ranged compared to atomic or molecular level forces.**
- Its influence can be experienced within the separation distance from 0.2 nm to over 10 nm.**

At the bottom of the slide, there is a video player interface with a progress bar at 1:31 / 29:55, a play button, and the text "INTERFACIAL ENGINEERING".

So, as you know, Van der Waals forces, meaning it has got three different, you know, forces which are nothing but, you know, the induced dipole-induced dipole, okay, which

is nothing but London or dispersion force, induced dipole-permanent dipole, which is also called as Debye and permanent dipole-permanent dipole, which is nothing but Keesom, right? So remember, when we deal with the Leonard-Jones potential in a previous lecture, we discussed that the attractive term, you know, which is inverse, you know, power law, you know, dependent on the separation distance, uh is nothing but it has got a pre-factor that is called b right that b comes from the β so the β is nothing but the uh you know the constant value the combination of all the constant values uh uh coming from the London and Debye and Keesom uh forces right so that is what I mean that that I mean that we have also I mean that we have described in the previous lecture itself so uh so that is uh you know very important uh you know to note So, now we will see see what are the you know the implications of these forces right. Sometimes you will only have to focus on one or two forces, not all three. For example, whether you deal with the polar molecule or nonpolar molecule, charged system or uncharged system. The London or dispersion force is always existing. This comes from the fluctuation in the electron density within the atom or molecules. So, you can expect this force always, right?

So, sometimes you might deal with the polar molecule together with non-polar molecule. So, there can be an interaction between polar and non-polar. In such case, you would expect an interaction between, I mean, interaction in the form of induced dipole and permanent dipole, which is coming under the Debye. force category ,the other one is the permanent and permanent dipole which comes from the molecule which has got dipoles permanently right for example acetone, acetaldehyde, HCl and all those things okay so uh as I as you can read from here, the Keesom force is because of the uh uh electronegativity right due to electronegativity Okay, so it is basically because of the permanent dipoles, right, between the molecules and that is due to the electronegativity and you can also understand that, you can also read that the induced dipole and permanent dipole, which is Debye force of attraction, is basically between polar and nonpolar molecules, right. So, in any case, Van der Waals forces are always attractive. So, we often use the sign convention negative to represent attractive force, positive to represent repulsive force.

So, it is always a relatively long-range force compared to atomic or molecular level forces. And more importantly, the Van der Waals forces of attraction is active within the separation distance between 0.2 nanometer to 1 nanometer. From 0.2 nanometer to 1 nanometer. So, which means that if let us say you have got molecules, right? So, if molecules are kept apart within a distance of 10 nanometer, then you can expect these three, all these three forces, you know, come into picture. Okay. Right.

(Time: 5:55 min)

Molecular interactions and power laws



- To understand the origin of the attraction between colloidal particles, it is necessary to consider the interactions between individual molecules, i.e. Macroscopic interactions are the summation of the pairwise interactions of the constituent molecules in the individual particles.

List of interactions between pairs of isolated ions and or molecules

Permanent dipole 1- induced dipole 2	$-\frac{(\alpha_{0,1}\mu_2^2 + \alpha_{0,2}\mu_1^2)}{(4\pi\epsilon_0)^2 x^6}$	$\alpha_0 =$ polarizability (always negative)	Debye
Permanent dipole 1- permanent dipole 2	$-\frac{2}{3} \frac{\mu_1^2 \mu_2^2}{(4\pi\epsilon_0)^2 k_B T x^6}$	Free rotation of dipoles (always negative)	Keesom
Induced dipole 1-induced dipole 2	$-\frac{3h}{2} \frac{\nu_1 \nu_2}{\nu_1 + \nu_2} \frac{\alpha_{0,1} \alpha_{0,2}}{(4\pi\epsilon_0)^2 x^6}$	$\nu =$ characteristic vibrational frequency of electrons (always negative)	London



So next we will look at the Inverse Power law, molecular interactions and Inverse Power law. If you want to calculate the interaction between two colloidal particles, spherical particle or non-spherical particle, or between two macroscopic objects like blocks, between two blocks, or between surfaces, one flat surface and the curved surface, all that, you can actually use this, you know, method of, you know, the calculating the pairwise interactions, right, between the molecules or particles, right, okay. So, as you know, there are three different types of forces under Van der Waals forces, okay. You can see that these three equations, right, Debye, Keesom and London, all these equations are Inverse Power law dependence. So, show all these three equations show Inverse Power law dependency on separation distance that is x . Remember we saw in the Lennard-Jones potential that is a B/x^6 right ok.

You can see the similar relation exists over here, here B is nothing but β which means that if you include all these constants right as within the bracket of β then you will be getting this β/x^6 right so yeah so this comes from the you know, you can now connect this with the potential that we have already described, right? So, these three forces equations, you can, the origin of this equation, if you want to understand this, the origin of this equations more in details, maybe you can refer to these two books which are, you know, given at the bottom below, okay, right? Now let's see, because these are the Inverse Power law equation, it can be applied whenever we calculate the pairwise interactions of molecules between the particles. Right. So first, let us understand the permanent dipole and induced dipole. So, Debye, you know, equation. So basically

London, let's start with London, basically the London force, which is always existing, right, which is always existing.

No matter whether you deal with, you know, charged system or uncharged system. Okay. It is because of the fluctuation in the electron density. Right. So that's how you get the London force always. So, let's say you deal with an atom which is, you know, neutral atom or argon. Let's say for an example, we can say argon. We deal with argon. and there is another neighboring atom which is also an argon when there is an interaction between the two, how they will interact, right, so as you know that each every compound has got its own electrons density within it okay it depends on the atomic mass or molar mass of the compound that we deal with, for example if you take an example of helium which has got only 2 electron, whereas argon has got about 18 electrons, right. So, the probability of argon atoms, okay, breaking the symmetry of distribution is highly likely compared to the helium because it has got only 2 electrons. Right. So, you can expect more of these, you know, the London dispersion force, in the case of argon will be more likely than the helium. Right. So, you can see how this is this dipole among these molecules are induced. Right. okay so you can see that there will be an atom if you come if you, you know, take an example of organ there will be a nucleus and then around it there will be electron density right electron cloud right so if electron cloud shifts one side right because they will be randomly moving around At some point of time, the electron cloud will be more on one side and less on the other side. So, you will have more electron cloud on one side and less on the other side. In such case, naturally, this molecule at one end, it will gain a net positive negative charge, right? There will be, it will gain a net negative charge on one hand and because of which it will gain net positive charge on the other end. okay and the similar way if other neighboring atom also experienced the similar change shift in the electron cloud then you can expect that they will interact via the so there can be net negative and net positive right so, sorry , I think so I want more electron cloud this side less electron cloud yeah So, let less electron cloud So more electron load this side, less electron load this side. So, you will have, again, net negative charge and a net positive charge. So, there will be electrostatic attraction between these two ends, right, where you've got net positive and net negative.

(Time: 11:51 min)

Molecular interactions and power laws



- To understand the origin of the attraction between colloidal particles, it is necessary to consider the interactions between individual molecules, i.e. Macroscopic interactions are the summation of the pairwise interactions of the constituent molecules in the individual particles.

List of interactions between pairs of isolated ions and or molecules

Permanent dipole 1- induced dipole 2	$-\frac{(\alpha_{0,1}\mu_2^2 + \alpha_{0,2}\mu_1^2)}{(4\pi\epsilon_0)^2 x^6}$	α_0 = polarizability (always negative)	Debye
Permanent dipole 1- permanent dipole 2	$-\frac{2}{3} \frac{\mu_1^2 \mu_2^2}{(4\pi\epsilon_0)^2 k_B T x^6}$	Free rotation of dipoles (always negative)	Keesom
Induced dipole 1-induced dipole 2	$-\frac{3h}{2} \frac{\nu_1 \nu_2}{\nu_1 + \nu_2} \frac{\alpha_{0,1} \alpha_{0,2}}{(4\pi\epsilon_0)^2} \frac{1}{x^6}$	ν = characteristic vibrational frequency of electrons (always negative)	London



Although it is because of the electrostatic attraction, eventually, the main reason for you know this attraction is because of the induced dipole- induced dipole that is because of the changes in the electron or fluctuation in the electron density, okay, you can give an example let's say organ right methane which is a non-polar molecule they will undergo this kind of an you know interaction London dispersion force is very common among these molecule or an atom right so we talk about the you know induced dipole- induced dipole you can also look at now what is known as permanent dipole- permanent dipole so one can give an example let's say we can take an example of acetaldehyde right if you take an example of acetaldehyde let's say you got acetaldehyde has got C = O within it, okay? Because the oxygen has got more electronegativity, it will hog more electron towards this, right? Towards it. So naturally, this will gain negative charge, right? Because oxygen atom is more electronegative and it can hog more electron towards it, right? And because of which, if the center of mass is somewhere here, there will be net positive charge somewhere on the opposite end. So, in this way, this molecule will carry permanent dipole within it.

(Time: 13:36 min)

Molecular interactions and power laws



- To understand the origin of the attraction between colloidal particles, it is necessary to consider the interactions between individual molecules, i.e. Macroscopic interactions are the summation of the pairwise interactions of the constituent molecules in the individual particles.

List of interactions between pairs of isolated ions and or molecules

Permanent dipole 1- induced dipole 2	$-\frac{(\alpha_{0,1}\mu_2^2 + \alpha_{0,2}\mu_1^2)}{(4\pi\epsilon_0)^2 x^6}$	$\alpha_0 =$ polarizability (always negative)	Debye
Permanent dipole 1- permanent dipole 2	$-\frac{2}{3} \frac{\mu_1\mu_2}{(4\pi\epsilon_0)^2 k_B T x^6}$	Free rotation of dipoles (always negative)	Keesom
Induced dipole 1-induced dipole 2	$-\frac{3h}{2} \frac{\nu_1\nu_2}{\nu_1 + \nu_2} \frac{\alpha_{0,1}\alpha_{0,2}}{(4\pi\epsilon_0)^2 x^6}$	$\nu =$ characteristic vibrational frequency of electrons (always negative)	London



Navigation bar with video controls: play, stop, volume, 13:36 / 29:55, CC BY-NC-SA, and other icons.

Now, the neighboring atom will also carry similar dipoles. So, when positive and negative dipoles interact with each other, there will be an attraction. So now, in this section, we will look at how to calculate the pairwise interaction between two semi-infinite blocks. So what is given here is the $W(r)$, which is nothing but the interaction right energy per molecule, this is basically, energy per molecule,

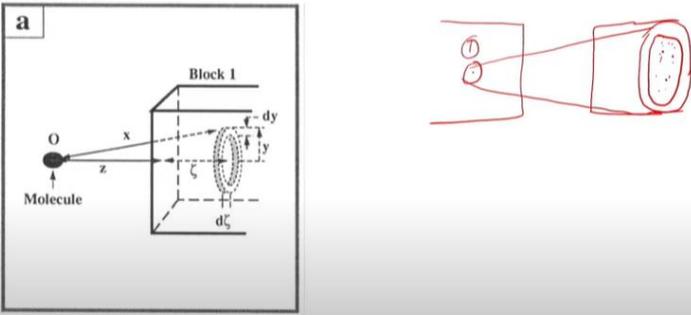
$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2 h\nu_1\nu_2}{2(\nu_1 + \nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$

So idea is if you know the pairwise interaction by summing up the interactions of all the molecules present between the block, two semi-infinite blocks then you will be able to, you know, obtain equation for this case, right, that is the exercise now we have got so now what we will do is remember you have the so the first approach will be So you have two blocks, right? Okay. So first we will look at the one molecule from here, and then we will consider in a region of space, a small control volume, right? Small control volume, right? Which is a ring-shaped control volume, okay, and if we consider this very small, tiny control volume, so in this region of space, in this ring-shaped control volume, you will have several molecules, right? The projection view of that will give you Okay, so you would be able to perform the pairwise interaction between this molecule, which is one, to several molecules present within this ring shift, right? Okay,

(Time: 15:33 min)

Calculating van der Waals forces between two semi-infinite blocks

First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2 h\nu_1\nu_2}{2(\nu_1+\nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$


The diagram shows a molecule (O) at a distance x from a surface element of area dy at distance r . The block is semi-infinite. A hand-drawn red diagram shows the geometry of the interaction.

15:33 / 29:55

INTERFACIAL ENGINEERING

So, once we know that, then by performing integration, right, from, you know, initial, from lower limit to upper limit, right, you'll be able to complete the pairwise interaction of entire block. okay so that is the idea and that is what also shown in this schematic, okay, so we will do that so first of all we know that when you want to do the sum total of all the, you know, molecular interaction, we know this is the function.

$$\int W(r) \times \frac{\rho N_A}{M_A} \times dv$$

So, if you perform this, basically you will be able to get the cover, all the molecules present within this region of space that is called dv , right? And then you will be able to calculate the pairwise interaction for all the molecules. So, in this way, you will get total energy, okay?

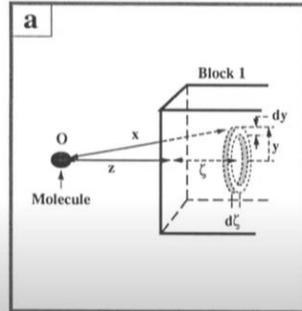
(Time: 16:50 min)

Calculating van der Waals forces between two semi-infinite blocks



First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2\hbar v_1 v_2}{2(v_1+v_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$



$$\int W(r) \times \frac{\rho N_A}{M_A} \times dv$$

↓
Total work



So that is the exercise we have to do. So, for here, let's consider this case, which is shown in the schematic already. Okay. In this case, how we can write, right? So, you can write this as, let's say we have

$$\int W(r) \times \frac{\rho N_A}{M_A} \times dv$$

- ρ - density
- N_A - Avogadro number
- M_A - molecular weight
- A' - molecules of particular species

We are considering between one molecule from another block to this ring-shaped. Why is this ring-shaped? Because we consider that the molecule which we take is spherical in shape, right? So, the projection view of that will be ring-shaped. That's why we consider this ring-shaped, you know, control volume, right? So, in this case,

$$\iint_0^\infty W(r) \cdot \frac{\rho N_A}{M_A} \cdot 2\pi y \, dy \, d\zeta$$

In this case, so if you if you you know perform this calculation what you will get is the pairwise interaction between right between this molecule and the control element present in the block 1, right that is very clear once we are able to do this then by performing integration from the lower limit to upper limit okay you will be able to consider or cover up all the molecules present within the block 1 that is the first exercise so we are breaking

down in this step into two first step will be to take care of the molecule from block 2 to the molecules, all the molecules present at the block 1. That is exactly what we are doing here. Okay. Right.

$$- \iint_0^\infty W(r) \cdot \frac{\rho N_A}{M_A} \cdot 2\pi y \, dy \, d\zeta$$

That will be minus because it's attraction. Okay. So now what we can do is, so what is $W(r)$? So that we must incorporate. Okay. So,

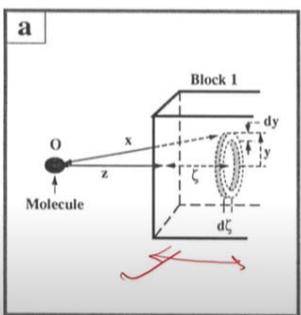
$$W(r) = \iint_0^\infty \frac{\beta}{x^6} \cdot \frac{\rho N_A}{M_A} \cdot 2\pi y \, dy \, d\zeta$$

So now all these things are constant.

(Time: 19:39 min)

Calculating van der Waals forces between two semi-infinite blocks

First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2 h\nu_1\nu_2}{2(\nu_1+\nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$


$$- \int_0^\infty \int_0^\infty W(r) \times \frac{\rho N_A}{M_A} \times 2\pi y \, dy \, d\zeta$$

$$- \int_0^\infty \int_0^\infty \frac{\beta}{x^6} \times \frac{\rho N_A}{M_A} \times 2\pi y \, dy \, d\zeta$$

19:39 / 29:55

INTERFACIAL ENGINEERING

We will keep the constant term outside. So, which means that you can keep this constant term outside. Then you will have

$$= -2\pi \cdot \frac{\rho N_A}{M_A} \cdot \beta \cdot \iint_0^\infty x^{-6} \cdot y \, dy \, dz$$

So if we can perform this, then we will be getting some idea, right, what is the pairwise interaction, right, in this, within this control volume. So, we know from the Pythagoras theorem, this x can be,

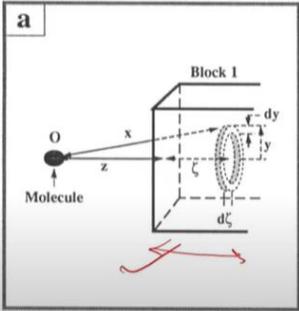
$$x^2 = (z + \zeta)^2 + y^2$$

So why we have done this way because It is easy for us to obtain the equation in terms of z, that is z direction, that is z. Why? Because it is easy for us to know what is the separation distance. So, your equation finally that you will be getting will be in terms of separation distance D, right? That you will see exactly how it is coming.

(Time: 21:12 min)

Calculating van der Waals forces between two semi-infinite blocks

First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2 h\nu_1\nu_2}{2(\nu_1+\nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$


$$-2\pi \frac{\rho N_A}{M_A} \beta \int_0^\infty \int_0^\infty (x^2 + y^2)^{-3} y dy dz$$

$$x^2 = (z + \zeta)^2 + y^2$$

INTERFACIAL ENGINEERING

So we will substitute this here. So in that case, you will be having,

$$= -2\pi \cdot \frac{\rho N_A}{M_A} \cdot \beta \cdot \int_0^\infty \int_0^\infty ((z + \zeta)^2 + y^2)^{-3} \cdot y dy d\zeta$$

Okay so by using the substitution method you can actually evaluate this integral that is nothing but let's say if I assume

$$z + \zeta = M$$

$$M^2 + y^2 = u$$

$$2y \, dy = du$$

$$y \, dy = du/2$$

(Time: 22:12 min)

Calculating van der Waals forces between two semi-infinite blocks

First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2\hbar v_1 v_2}{2(v_1+v_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$

a

$$-2\pi \frac{\rho N_A}{M_A} \beta \int_0^\infty \int_0^\infty (x-z)^{-6} y \, dy \, d\zeta$$

$$-2\pi \frac{\rho N_A}{M_A} \beta \int_0^\infty \int_0^\infty \left[\frac{1}{2} (z^2 + y^2)^{-3} y \, dy \right] d\zeta$$

$$M^2 + y^2 = u$$

$$2y \, dy = du$$

INTERFACIAL ENGINEERING

Now integral will be going from instead of 0 to ∞ , it will be going from $M^2 \rightarrow \infty$. Right.
Yes. $M^2 \rightarrow \infty$. Right

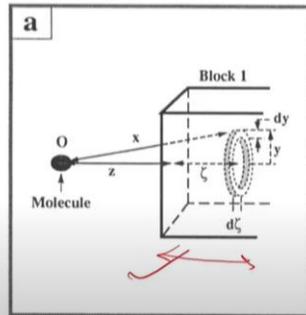
(Time: 22:34 min)

Calculating van der Waals forces between two semi-infinite blocks



First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2 h\nu_1\nu_2}{2(\nu_1+\nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$



$$-2\pi \frac{\rho N_A}{M_A} \beta \int_0^\infty \int_0^\infty (x-\zeta)^{-6} y dy d\zeta$$

$$-2\pi \frac{\rho N_A}{M_A} \beta \int_0^\infty \int_0^\infty \frac{1}{(z+\zeta+y)^2} y dy d\zeta$$

$M^2 + y^2 = u$
 $2y dy = du$
 $y dy = \frac{1}{2} du$



So if you perform this equation I mean in this way after substituting the this as u, z + \zeta as M, M^2 + y^2 as u you will be able to get the the required you know you will be able to perform required integration and get the the the final answer you will be getting is you can also verify, that will be

$$= -2\pi \cdot \frac{\rho N_A}{M_A} \cdot \beta \cdot \int_0^\infty \frac{1}{4(z+\zeta)^4} d\zeta$$

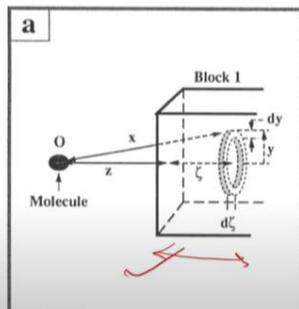
(Time: 23:26 min)

Calculating van der Waals forces between two semi-infinite blocks



First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2 h\nu_1\nu_2}{2(\nu_1+\nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$



$$-2\pi \frac{\rho N_A}{M_A} \beta \int_0^\infty \int_0^\infty (x-\zeta)^{-6} y dy d\zeta$$

$$-2\pi \frac{\rho N_A}{M_A} \beta \int_0^\infty \int_0^\infty \frac{1}{(z+\zeta+y)^2} y dy d\zeta$$

$$-2\pi \frac{\rho N_A}{M_A} \beta \left[\frac{1}{4(z+\zeta)^4} \right]$$



So now if you perform this again, let's say, you know,

$$= -2\pi \cdot \frac{\rho N_A}{M_A} \cdot \frac{\beta}{4} \cdot \int_0^\infty \frac{1}{(z + \delta)^4} d\zeta$$

So, you have to evaluate this integral again. so again, you can substitute this

$$Z + \zeta = u$$

$$d\zeta = du$$

the limit will be going from instead of $0 \rightarrow \infty$, it will be going from $z \rightarrow \infty$ so that is exactly you have to substitute here so if you substitute again you will get the uh the equation the final equation will be

$$= -2\pi \cdot \frac{\rho N_A}{M_A} \cdot \frac{\beta}{12 \cdot z^3}$$

So, this is exactly what the the integration after performing the integration you will have

$$= -\frac{\rho N_A}{M_A} \cdot \frac{\beta \pi}{6 \cdot z^3}$$

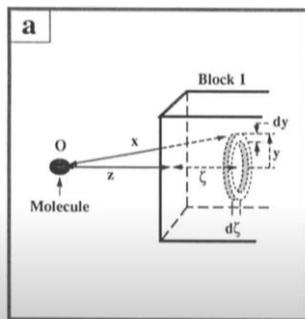
(Time: 25:07 min)

Calculating van der Waals forces between two semi-infinite blocks



First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2 h\nu_1\nu_2}{2(\nu_1+\nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$



$$-2\pi \frac{\rho N_A}{M_A} \frac{\beta}{4} \int_0^\infty \frac{1}{(z+\delta)^4} d\zeta$$

$$-2\pi \frac{\rho N_A}{M_A} \frac{\beta}{12 z^3}$$

$$-\frac{\rho N_A}{M_A} \times \frac{\beta \pi}{6 z^3}$$

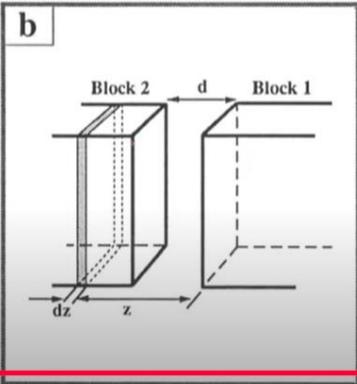


Now it is not done, so what we have to do further, so you need to again, there is another one, right? So, we have now taken care of one molecule and then we summed the pairwise interaction, we can perform the pairwise interaction, you know, within the, you know, molecule present in the block 1, right? Now we need to do the same exercise for the block 2, right so now how do we do remember ,we uh

(Time: 25:44 min)

Calculating van der Waals forces between two semi-infinite blocks

First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2\hbar\nu_1\nu_2}{2(\nu_1+\nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$


25:44 / 29:55

INTERFACIAL ENGINEERING

So, imagine we are going to cut this small slice right from this okay and in that small slice you have molecules present, right, ok. The advantage here is the molecules, all these molecules are at the same distance, which is same separation distance d. In that case, what you can do, since we have already calculated for one molecule in this case with all the molecules present in block 1, By multiplying the number of molecules present within this slice, the small slice of block 2, you'll be able to calculate the pairwise interaction of all the molecules between block 1 to the small slice, the thin slice of this block 2. In that way, you'll be able to get the pairwise interaction up to this point, right? Right. So that is exactly we will do.

$$= - \left(\frac{\rho N_A}{M_A} \right)^2 \cdot \frac{\beta \pi}{6}$$

So this is exactly what we have. Now, by performing integration from this point up to whatever extension, I mean, to whatever extent that is required. For example, it can be from d. So this is the d is the separation distance. So from d

separation distance to, you can go up to any astronomical distance that is ∞ . If you perform integral, okay, in this case, let's say if I perform integral, between $d \rightarrow \infty$,

$$= - \left(\frac{\rho N_A}{M_A} \right)^2 \cdot \frac{\beta \pi}{6} \cdot \int_d^\infty \frac{1}{z^3} dz$$

In this way I will be able to obtain the pairwise interaction of all the molecules present in the block 2 as well as block 1, so that is what exactly uh we wanted to do and that is exactly what we are going to do okay so So in this way, what you will be obtaining is

$$= - \left(\frac{\rho N_A}{M_A} \right)^2 \cdot \frac{\beta \pi}{12} \cdot \left[\frac{1}{d^2} \right]$$

So by performing this, you will be getting as $1/z^2$. So it will be $2z^2$. So you will have, this will be 12. So finally, you will get 12. OK, so now if I assume that there is something called Hamaker constant, so if I assume Hamaker constant as capital A, and so all these things I can put into this bracket. So I can call this Hamaker constant as

$$A = \left(\frac{\rho N_A \pi}{M_A} \right)^2 \beta$$

So since I have taken one additional π and put it in the inside the bracket, so I just have to also add one more π in the in the denominator right so this is nothing but Hamaker constant okay

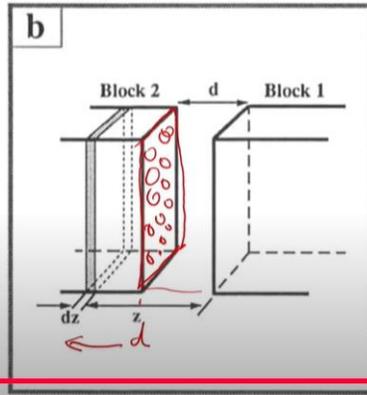
(Time: 28:52 min)

Calculating van der Waals forces between two semi-infinite blocks



First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2 h\nu_1\nu_2}{2(\nu_1+\nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$



$$-\left(\frac{\rho N A}{M A}\right)^2 \frac{\beta \pi}{6} \int_0^{\infty} \frac{1}{z^3} dz$$

$$-\left(\frac{\rho N A}{M A}\right)^2 \frac{\beta \pi}{12} \left[\frac{1}{z} \right]_0^{\infty}$$

$$A = \left(\frac{\rho N A \pi}{M A}\right) \beta$$



So in this way I can rewrite this equation the old equation as So then whole equation as

$$\phi(r) = -\frac{A}{12\pi d^2} \quad (\text{A-Hamaker constant})$$

So this is how you can calculate the pairwise interaction of any two macroscopic bodies, which are made up of its own constituent molecules.

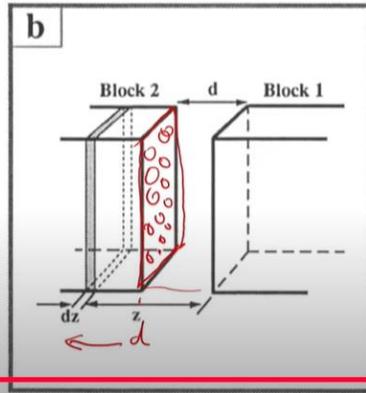
(Time: 29:38 min)

Calculating van der Waals forces between two semi-infinite blocks



First we will calculate an interaction between molecule and a block of material

$$W(r) = \frac{1}{(4\pi\epsilon_0)^2 \cdot x^6} \left(\frac{3\alpha_1\alpha_2 h\nu_1\nu_2}{2(\nu_1+\nu_2)} + \frac{\mu_1^2\mu_2^2}{3k_B T} + (\mu_1^2\alpha_2 + \mu_2^2\alpha_1) \right) = \frac{\beta}{x^6}$$



$$\phi(r) = -\frac{A}{12d^2}$$

Correction:
 $-\frac{A}{12\pi d^2}$

$$-\left(\frac{\rho N A}{N A}\right) \frac{\beta \pi}{12} \left[\frac{1}{2} \frac{1}{d^2} \right]$$

$$A = \left(\frac{\rho N A \pi}{N A} \right) \beta$$



29:38 / 29:55

INTERFACIAL ENGINEERING

So I think it would have been very clear to you. We will stop here. We will continue from the next lecture. Thank you.