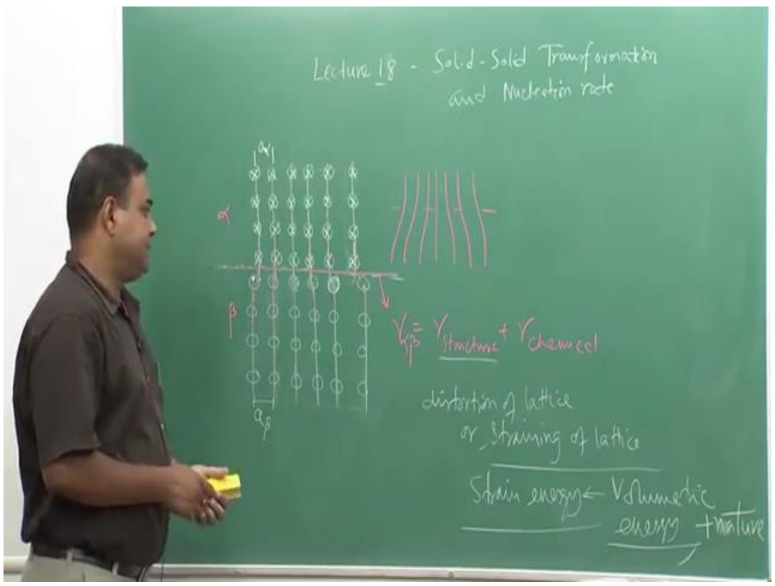
Heat Treatment and Surface Hardening (Part–1)
Professor Kallol Mondal
Professor Sandeep Sangal
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur
Lecture Number 18
Solid-Solid Transformation and Nucleation rate

Let us start our lecture on solid transformation and nucleation rate.

(Refer Slide Time: 00:30)



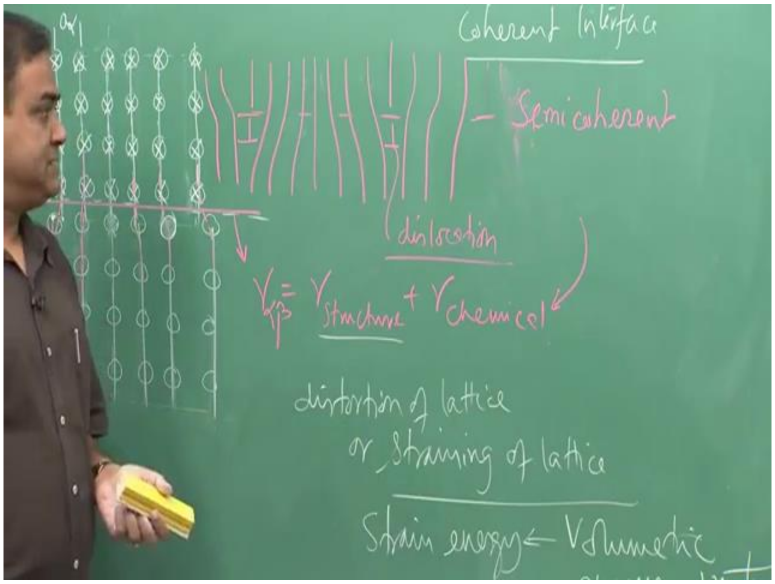
And it is the lecture number 18 and as we are discussing thst how this straining of lattice takes place in order to have a match between lattices between of parent and product phase. This is my (product) parent phase and this is my product phase that mean beta is appearing in the solid alpha both the phases are solid.

Now uhh when this kind of lattice mismatch (mi) matches there. For example in case of copper silicon system we have seen that the (())(00:54) phase and alpha phase both have perfect lattice match along 111 as well as 001 plane for HCP as well as for FCC. And at the same time the angles this direction for those planes 110 as well as 112 bar 0 they are having uhh match uhh they are parallel also.

So that time we have a perfect lattice match and that time the chemical energy, chemical (che) interface energy uhh would be the interfacial energy but in this case there would be two factor one is chemical because of the compositional changes as well as there is a structure affect. And the structure affect is coming due to uhh this lattice training part and this lattice train is leading to the strain energy and which is volumetric in nature.

At the same time these are the positive nature, ok. Now uhh interestingly this particular interface as well as in case of copper silicon where we have a perfect match we call it coherent interface, this is coherent interface. Now situation would be uhh different let us say we are having match like this, because of the straining of the lattice. But at some point of time this particular bending will not be allowed.

(Refer Slide Time: 02:00)



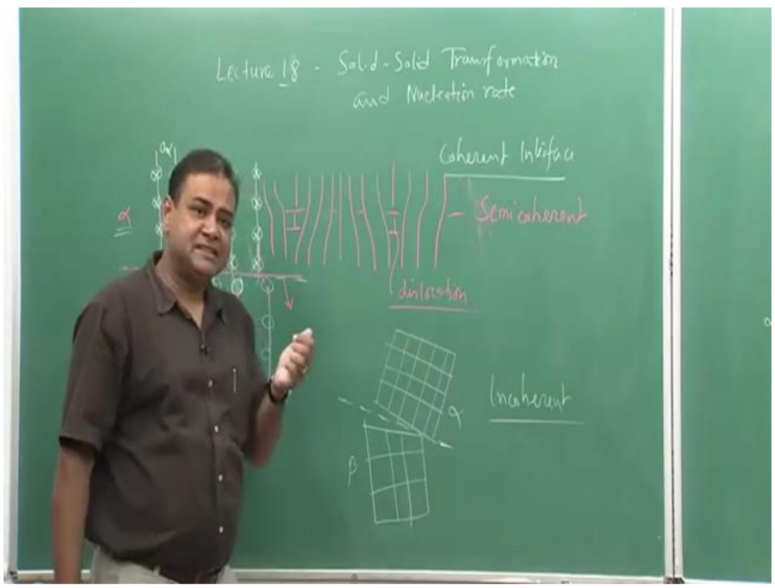
If it request too much of bending. So that time it will create another situation which is called incoherent interface. So now these are the matching part, but if further bending is not allowed then if this is the further bending it required. So this much bending it is if it is not allowed, that time the lattice of the parent phase would not have anything below rather it will start like this, ok.

So now this is an extra plane on top of this particular line and this is looking like this. So this is a kind of dislocation. So whenever this extra strain energy which is required for the lattice bending, ok. That is not permitted, so then that much of energy will be stored in the form of dislocation. So there will be extra lattice plane on top of this particular interface and there will be no plane below this.

And then again the situation will continue at some point of line there will be another lattice plane like this which will be again uhh uhh this kind of situation uhh so this there will be another situation like this there will be another uhh lattice plane on top of this, this is another dislocation. So like that way there will be uhh creation of dislocation along this particular interface in order to take care of that extra (lat) lattice distortion, ok.

So that time it is called incoherent uhh semi coherent, semi coherent. And that time it will be again part (of) again this particular this interface will have two contribution one is structure, one is chemical. And this structure contribution would lead to the strain energy of the lattice.

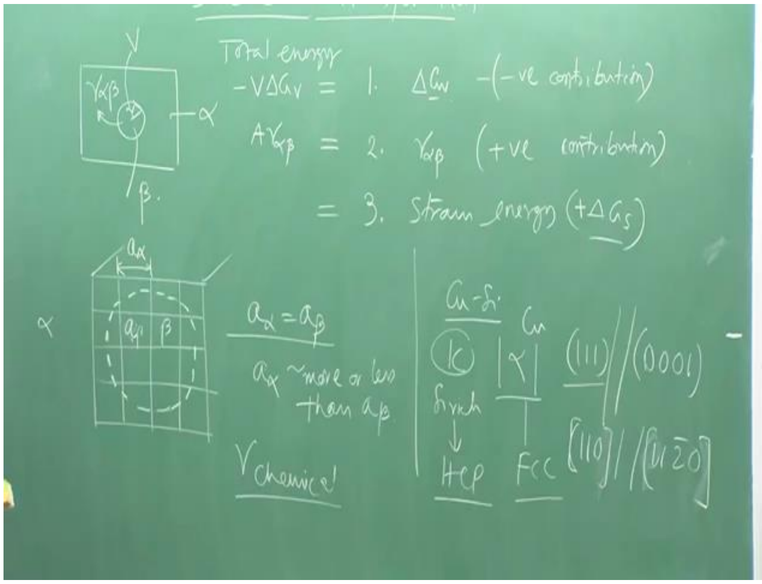
(Refer Slide Time: 05:01)



And similarly there will be one more interface which is which we call as incoherent interface. And that time there will be no lattice match between the parent and product phase. So if we have a situation like this, if this is the lattice alpha, if this is the lattice alpha there will be one other lattice of beta. This is beta, this is alpha let us say and this is the interface that time there will be no match, mismatch between the lattice planes and that time it is called incoherent.

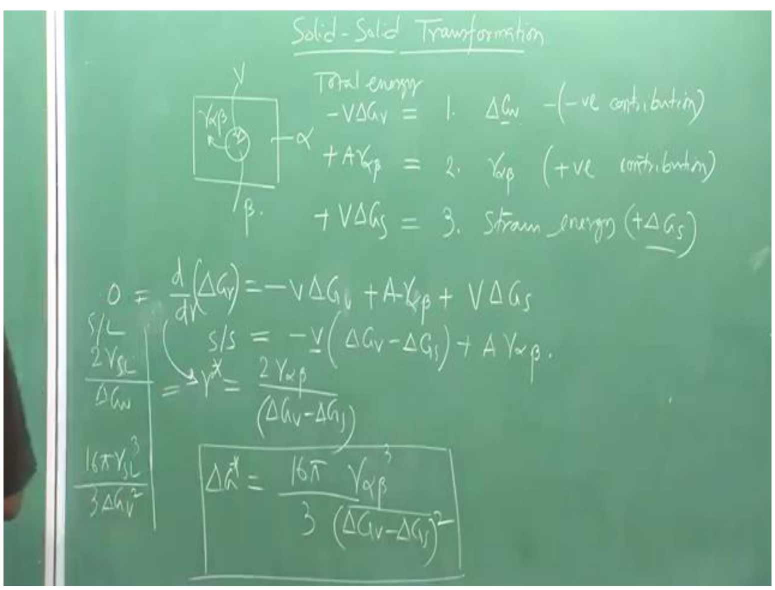
Now it is pretty clear that here the energy of the interface would be very high, here it will be in between and here will be the lowest. But still there would be existence of strain in energy.

(Refer Slide Time: 05:37)



And this strain energy is coming into picture because here we are considering solid solid transformation. And once we know that then the procedure is exactly similar what we have followed in case of liquid solid transformation that time this would be the energy. So this is again volume term delta GS which is positive, ok. This is also positive.

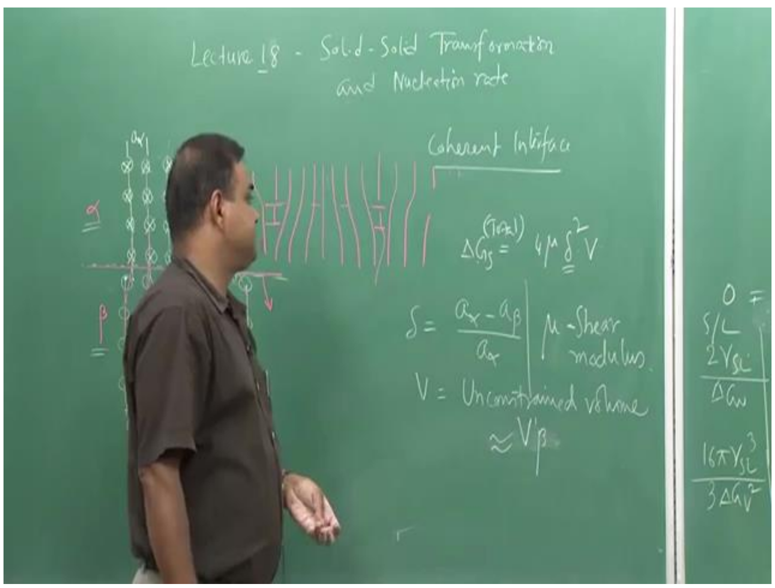
(Refer Slide Time: 06:00)



So now if I try to find out free energy change total free energy change, it would be minus V if we do this delta GS. So it would simply like and now if this is spherical, if we consider this is a spherical of radius r so that time we can calculate what is the critical radius, critical radius would be 2 gamma alpha beta divided by delta GV – delta GS, if we do that that means if we do that equal to 0, you will get to this, ok.

So once you get this delta G star also you can calculate which would be 16 pi 3 gamma alpha beta cube delta GV – delta GS square, ok. And now this is the expression for activation barrier. Now in this case activation barrier, now if we compare with the solid liquid case there, there were no delta GS term. So it was simply gamma liquid SL divided by delta GV and that time this is solid liquid case and this is solid solid case and this one was delta GV square.

(Refer Slide Time: 08:40)

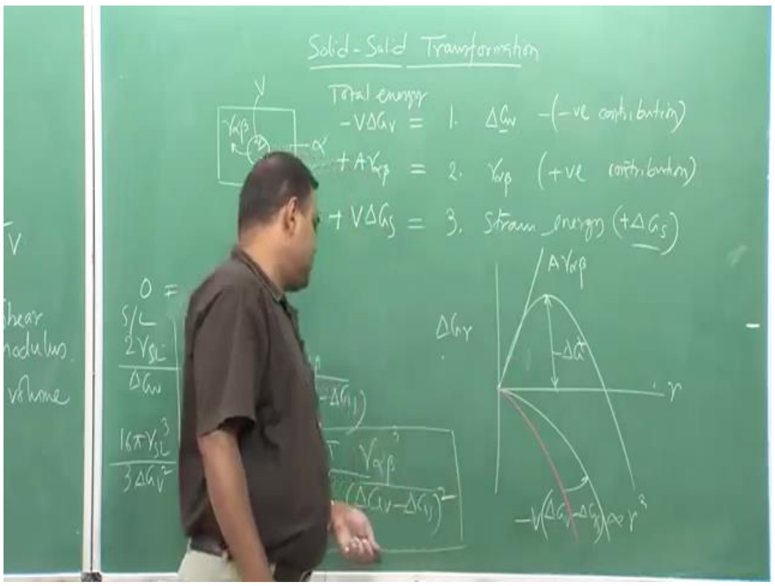


So only thing that is the difference is basically delta GS, now we can also calculate delta GS. For example in case of uhh coherent interface we have a simple expression which is delta GS, which is total here total equal to 4 Mu delta V delta square V. And here delta is the strain energy and delta is related to a alpha, ok. So this a alpha this is a alpha, this is a beta and this is the relation.

And Mu is basically Shear modulus. And V is the equal to volume of beta, ok. So that means the share modulus you can get from any material which is basically the uhh CS train divided by uhh uhh CS stress divided by CS strain. And this you can also calculate from the lattice parameter and then you can get the delta GS term and you will see it is a volume multiply that means the volume factor.

So now you can see that uhh this is simple expression for uhh calculation of strain energy in case of coherent strain uhh so you can use that particular formula and to get uhh some idea about r star and delta G star. And once we get that we can have a kind of graphical representation. If I try to see the graphical representation uhh I can also have that, ok.

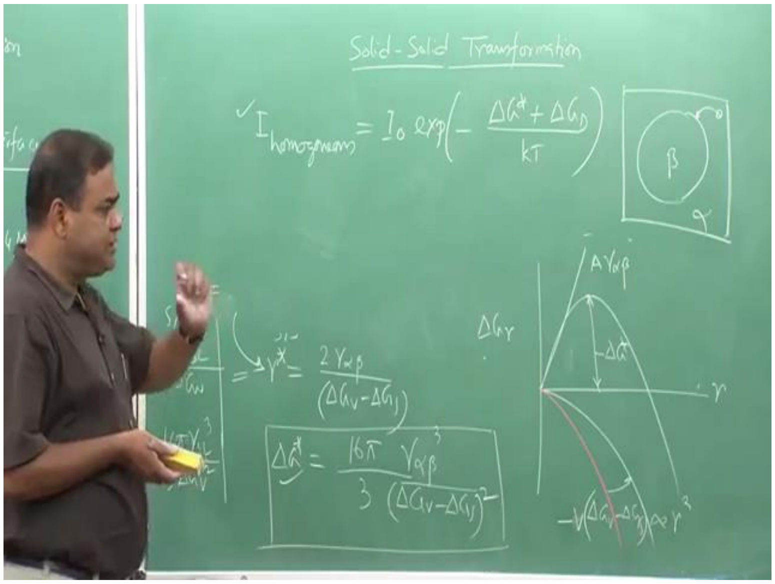
(Refer Slide Time: 10:04)



So the last time what we have done uhh this is my r and this is my delta Gr, so it varies like this. And that time this is my A gamma alpha beta and there be two term this was be my delta GV – delta GS, with a negative sign V negative sign is proportional to r cube. But if I try to find out and this delta G star which is nothing but this is decided by this, but if I try to consider delta GV only that one would vary like this. So the if I consider this one, this entire thing would go to the left, ok.

So it would appear on the left side, so this is the kind of energetic situation uhh when we consider strain energy. The strain energy is actually takes the uhh this point towards right right, ok. So uhh if I consider the homogeneous nucleation that times I do come across this.

(Refer Slide Time: 11:30)



And if I try to find what would be the homogeneous nucleation rate would be equal to it would exact would also have a similar expression which is minus delta G star plus delta GD by KT, where D is delta G star is given here, ok.

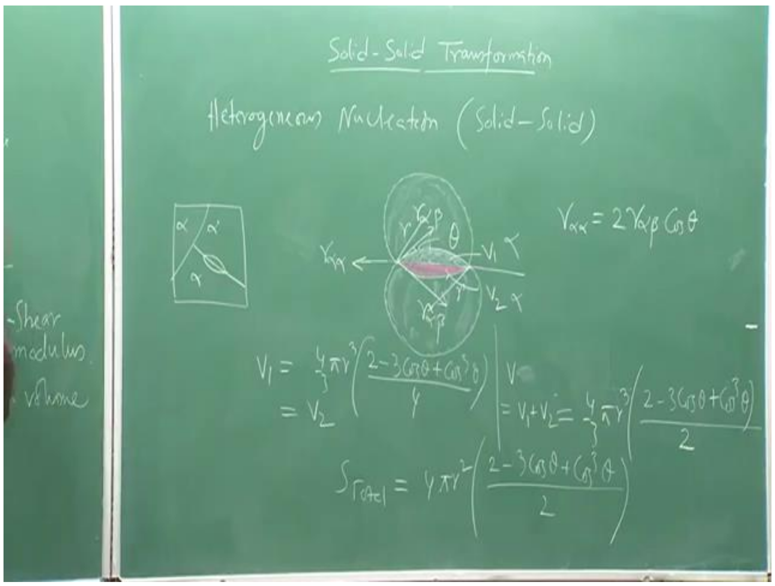
And this delta GD is basically for example if we have beta in alpha, in alpha this alpha atom when it starts and go to when we when it migrates and go uhh goes to the beta surface that time we have to come across another energy barrier which is delta GD which is coming from the diffusion factor, ok. So that means I homogeneous has got a similar expression what we had in case of I homogeneous for solid liquid transformation, ok.

So now this is about uhh uhh homogeneous nucleation in case of uhh uhh alpha beta transformation and that too that is happening at uhh uhh uhh that happening at temperature below uhh equilibrium temperature, ok. And uhh uhh we if we know this expression uhh then we can calculate what is the homogeneous nucleation which is number of nuclei per unit volume per unit time.

And this information will be required in order to construct TTT diagram because our final aim is to find what is the TTT diagram, which will allow us to go for a different temperature time sequence in order to get different structures in materials. Now once we know homogeneous one we can also have a similar expression uhh like (hetro) in case of heterogeneous nucleation.

But in case of heterogeneous nucleation treatment would be similar but with a little difference that there uhh it is not the solid will not form on the mould world rather it will form it can also form on grain boundaries, ok. So let us have a uhh look at the homogeneous nucleation part, sorry heterogeneous nucleation.

(Refer Slide Time: 13:45)



In case of heterogeneous solid to solid that time I can have many things in the materials, which can act as a sight for heterogeneous nucleation to occur. For example there could be oxide particles during solidification it can interrupt intrusions which can be in the form of oxides which can stay inside the solid, ok. That can act as a uhh heterogeneous nucleating sites. For example there could be grain boundaries, in a polycrystalline uhh material where there would be grain boundaries one grain boundary can act as a heterogeneous nucleating sites.

Let us consider that one grain boundary act as a heterogeneous nucleation site and that time this is alpha, this is alpha in the beginning. In the beginning it was alpha alpha that means both the phases this is alpha, this is alpha, this is alpha. And let us say one beta phase appears, ok and the beta phase appears in the form of two spherical cup, two truncated spherical cup and if I continue this particular cup.

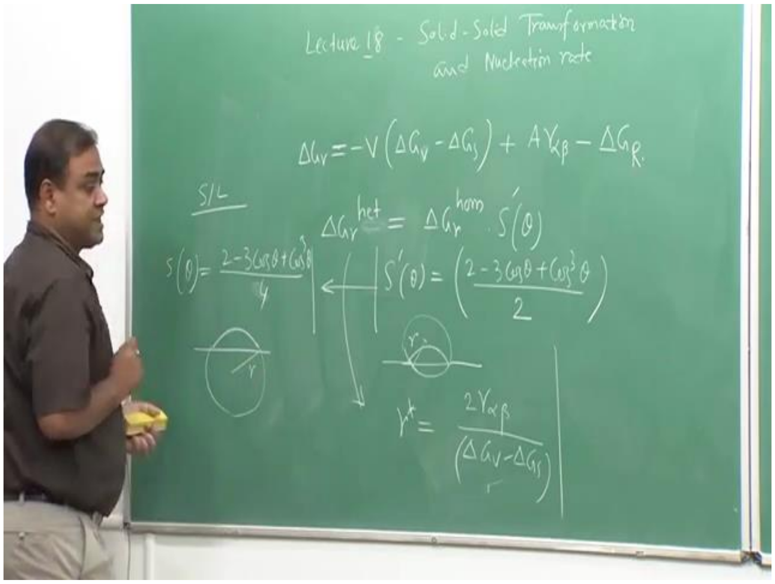
So this is one sphere, this is another sphere but this part is not there and this part is not there, so only this part is there. So as if two truncated (speri) spherical cups are connected together and it forms a lens, ok. Now here if we see that the center part where this alpha beta interface was existing that interface is out, ok. So now we have three interfaces one is this gamma alpha alpha, this which is gamma alpha beta and another one is this gamma alpha beta.

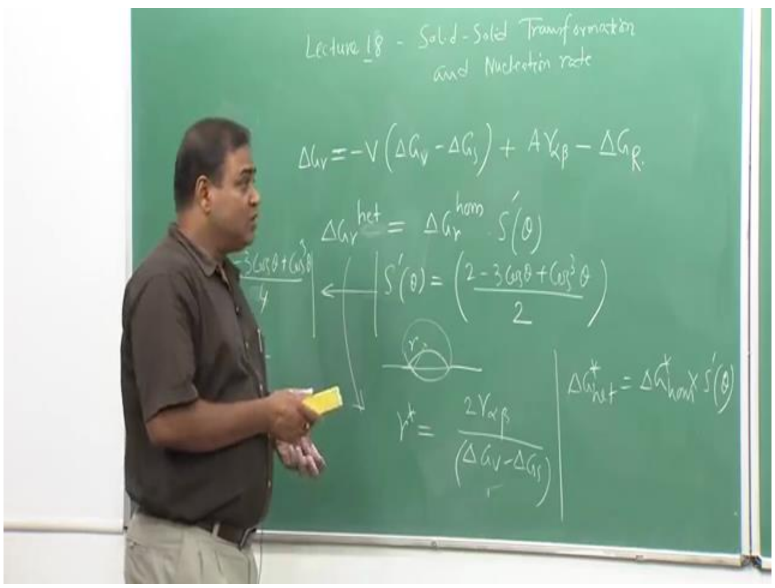
So now we can have this situation where I can make them as a vector quantity and then these are the forces, I can also convert in terms of surface tension. Because surface energy can also be a surface tension, ok. So that time I have this is the parting line, this is the theta which is the contact angle. So that time the situation is little different because energy situation, energy equilibrium situation alpha (())(16:38) 2 gamma alpha beta Cos theta, ok.

So now again I can individually calculate the volume of this, volume of this top part, volume of top part as well as the volume of bottom part, volume of bottom part. From the the way we have done it for solid liquid interface when heterogeneous nucleation was taking place. So now if I consider this one, this one the volume would be again say similar it would be uhh this particular volume would be uhh.

So that means this volume and this volume would be similar because two having the same radius, if this is the center, this is also r. So both are having the same radius, so the V1 if this is V1, this is V2 so V1 would be equal to V2. And that time the total V would be 2. Now if we try to find out the total surface area again it would be total 2. This is the total so that means that is S1+S2.

(Refer Slide Time: 19:40)





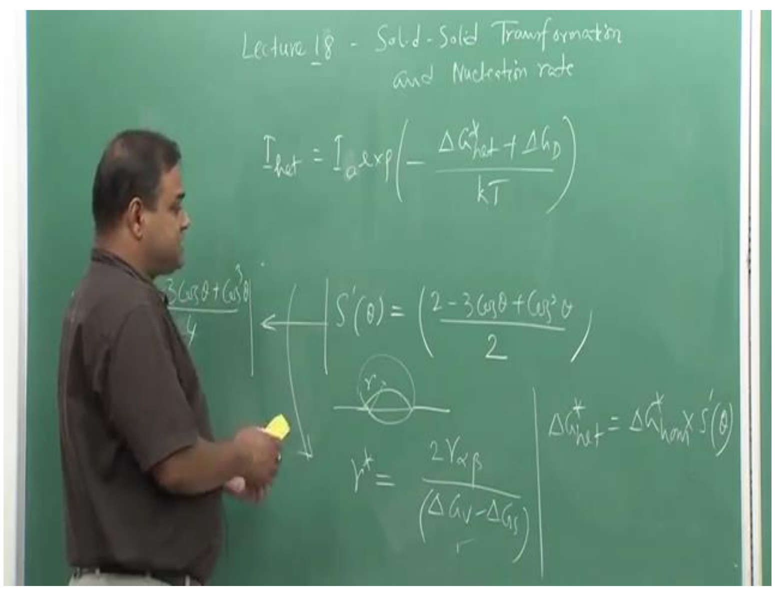
Now interestingly if I try to uhh do the same treatment the way we have done for heterogeneous nucleation. The expression would be, so this delta GR with a negative sign I mean to say that one interface is out. Whenever some heterogeneous nucleation is taking place one interface is destroyed and or removed that is what I have put delta GR which is the removed interface which contains the total surface area also.

Now if we do the same treatment the way we have done for heterogeneous nucleation in case of liquid solid we would get delta Gr heterogeneous would be equal to delta Gr homogeneous is theta. And that time S prime theta would be equal to 2. So in that case and the previous case where there were no uhh such situation that two thing two lenses are forming. There is a only one lens were forming, was forming, so that time in case of solid liquid case S theta was 2, here it was 4.

Because now that was consider in terms of one such cup and here it is two such cup. So that is why this 2, 4 is replaced by 2, but the other things remain same. Now interestingly if we have some contact area, ok uhh sorry contact theta, there is existence of theta which is less than 90 degree if I have that case delta Gr heterogeneous would be less than delta Gr (he) homogeneous.

And from that we can also get r star would be similar like delta Gs as well as since r, this r and so in this case if we consider this r, this r and in this case this r both are same. So that is what r star would not vary, the only thing that varies is S prime theta, ok. So now you carry out this (ex) exercise you would see that delta G star heterogeneous would be equal to delta G star homogeneous into S prime theta. And S prime is nothing but this, ok.

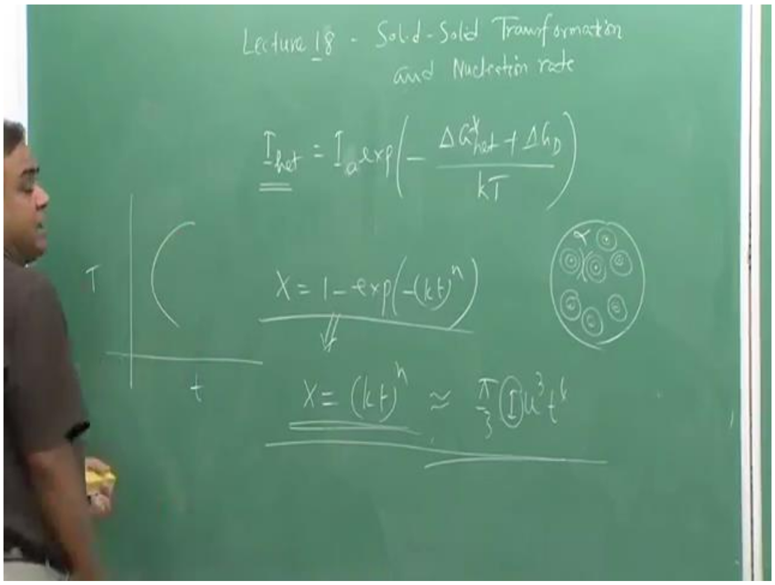
(Refer Slide Time: 23:20)



So now at the same time we can also relate the heterogeneous nucleation rate which will be again the similar, it will be again similar. So now we can see that whether it is a solid solid transformation or it is a solid liquid transformation we can get to the value of nucleation rate.

Now we have found nucleation rate for both the situation, ok. Uhh whether it is a solid liquid or solid solid and at the same time whether it is a homogeneous or whether it is heterogeneous, ok.

(Refer Slide Time: 24:15)



So that means once we know this one term is known in in our uhh expression for overall kinetics. And if we try to see uhh very very small quantity of phase which is forming that means if we consider that the beta phase formation is pretty small, ok. So that time I can say that X equal to kt to the power n, we can convert into power law and we can also relate it to t to the power 4 and where I is the nucleation rate which is this.

Now and this is in the case where I have a very small fraction forming in the parent phase, ok. And that is what we do not have any impingement affect between the phases. For example let us say if this is the volume where phase transformation is taking place is this is alpha and let us say the beta is appearing like this, like this. So that time the fraction of beta would be very very small across the total volume.

And then these beta will start growing. But until unless it reaches to a sufficient size, these two grains will not interact between each other. And whenever this interaction comes that time this two spheres would actually try to impinge each other. So that impingement factor would come in the form of this exponential term. But if there is no impingement then it would be power law.

This entire thing will be uhh (talked) will be uhh will be thought by uhh process angle, ok. So I am not getting into that but at least you are clear that why we were interested in finding out I, because in order to find the overall crystallization overall the transformation kinetics and this particular expression would get me TTT diagram, ok. So that is what we wanted to do all those treatments.

Now once we do this we have to find out one more thing which is u, ok u is equally important because until unless we do not know u, we cannot get the information of transformation as a function or time at a particular temperature T, ok. So our discussion will be on u how to find out growth rate, that means when this nuclei would start growing that information we need to uhh understand.

And the second part whatever we have considered till now this is with reference to single component. We have to get to the multi component and we will go to the binary system first. In the next class we will start with a binary system and then we will see the how in case of binary this nucleation rate factor is (takel) is tackled, ok. Let us stop here we will continue in our next lecture, thank u.