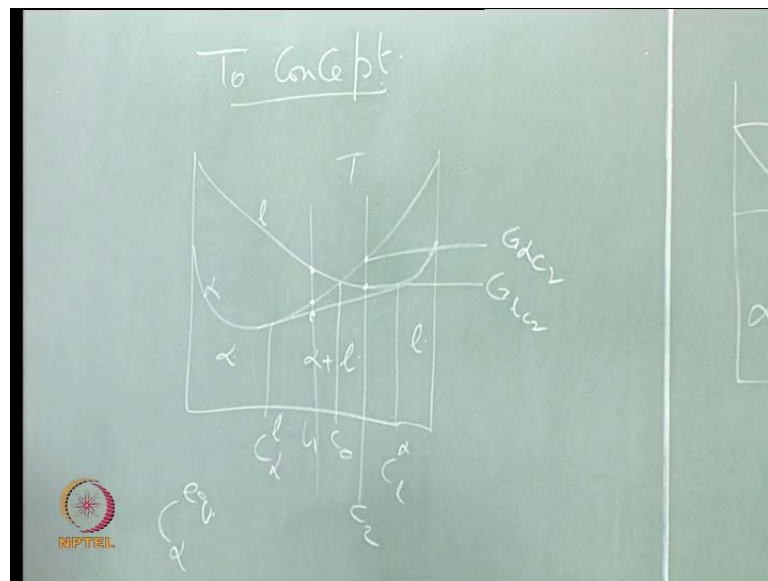


Advanced Metallurgical Thermodynamics
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Lecture No. #10
To concept, partition less solidification

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Last class we were talking about, what is called a concept, which we usually called it as T naught concept, we did not use this term in the last class. We will use it today, what we were talking about is taking a free energy composition diagram, something of this sort for two phases call it as, let us say a alpha, and liquid two phases. In a phase diagram which is something like this, this side is liquid, so this is wrong. So, the phase diagram should be like this, can you tell me why did I say this is wrong, the previous one.

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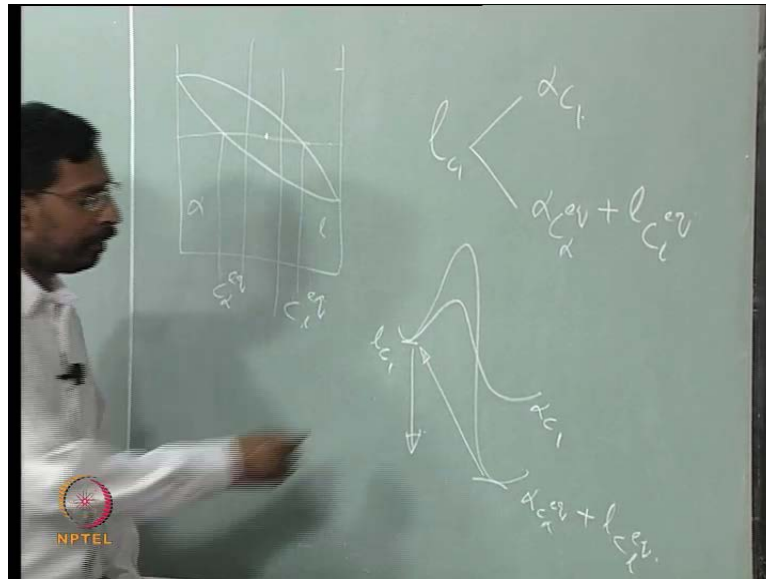
So, you have to have liquid stable on this side, pure b side liquid should be more stable at this temperature at which we are drawing. And our temperature is something like this let us say, so at that temperature, if I extend this temperature line to both the sides, I should see that on the pure b side, liquid should be stable at that temperature, that is the meaning

of this common tangent. If I draw a common tangent like this, the two points that you are going to get here, within this two compositions, which are called the C alpha liquid, C liquid alpha. Of course, some people even called it as equilibrium, C alpha equilibrium, C liquid equilibrium; obviously here, because when I say C alpha, it is obviously in equilibrium with liquid only, there is nothing else, but when there are three phases, then you have to specifically say it is in equilibrium with what?

For example, we are going to come to eutectics in a few minutes and once we come to eutectics, there you have to clearly say, alpha composition that you are talking is it in equilibrium with liquid or is it in equilibrium with beta. In this particular phase diagram, because it there is only liquid that is left out, other than an alpha. If you simply say C alpha equilibrium, if you write like this, it means it is the equilibrium composition of alpha at that temperature and whenever we say equilibrium, it is obviously with respect to some other phase, what is the second phase? It is the liquid. So, when I say C alpha equilibrium or C alpha liquid basically I am talking of the same, in this particular context.

In this context of where **where** there are only two phases, so basically they are kind of synonymous, so we can call either C alpha equilibrium or C alpha in equilibrium with liquid. So now, if you take these two points between these two, it is alpha plus liquid that is in equilibrium and to the left of it, we had already seen, that it is alpha in equilibrium and to the right of it, it is the liquid in equilibrium; that means at that temperature, if I extrapolate that tie line, towards the pure a and pure b.

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You should see that to the left of this, there should be alpha in equilibrium and to the right of this, they should be liquid in equilibrium. And between these two, it should be alpha plus liquid, that is how, there is one to one correspondence between the free energy composition diagram and the phase diagram. Exactly, you should see these two compositions should match with these two compositions and on the left side, it should be alpha and on the right, it should be the liquid. And that is where, you will see, if I draw the phase diagram like this, this would not correspond to with this, otherwise you can always do, because this is anywhere schematic, I will simply replace l with alpha, alpha with l, change the free energy curves than also it would good, it would do good. So, once you draw this free energy composition diagram first then if you are drawing the free energy phase diagram. It should be this phase diagram rather than that phase diagram, so this has to be remembered.

Now, what we are talking about is, we were talking about this particular composition, which we will called it as C_{naught} composition and we saw what would happen, if I choose any alloy and that C_{naught} composition, I can put it on this phase diagram somewhere here, need not be exactly at the centre, depends on how the free energy curves are, but it is definitely between C_{alpha} equilibrium composition and C_{liquid} equilibrium composition it has to be between these two and if I choose any alloy to the left of it and bring it to that temperature, from it is high temperature from the single phase liquid state, I melt this liquid, bring this liquid to that temperature and hold it there.

And think what should happen, that is where we have said, that particular liquid has two possibilities. One this liquid of that C_1 composition, can become alpha of C_1 composition because, if I choose a composition like this, C_1 I call it, that C_1 composition will have a free energy of this, is what we have seen in the last class. And that can come to either alpha having this composition or alpha plus liquid having this composition, one minute let me close this. (no audio from 05:50 to 05:56) So, this is the second possibility, what is the second possibility, it can give you alpha of C_1 equilibrium plus liquid having C_1 liquid equilibrium composition. These are the two possibilities, yesterday we have seen in the last class.

And then we said, if you are cooling the alloy under equilibrium conditions; that means, the time available is very large then the second possibility will hold good. The liquid having that composition will split the composition, will split into these two; that means, we call it as partitioning taking place; that means the composition the peak atoms, which are there inside the liquid get partition between alpha and liquid. And that is how, you get alpha having a different compositions as that of the starting composition, liquid having a different composition as the starting composition. This would come out provided you are close to equilibrium, if you are far from equilibrium; that means, the time available is very very short then in such a case, you would see that, you get the liquid having C_1 composition, would try to become alpha of C_1 composition. This is what we called it as, partition less solidification, there is no partitioning taking place during this, because the composition of the liquid, composition of the alpha is exactly the same expecting that there is only a structural change that is taking place and such transformation are usually called as polymorphous transformation, it is a general terms, whereas as for as solidification is concerned, we call it as partition less solidification.

Now, we also saw, that if I take an alloy on right side, what would happen; that means, look at again, this free energy composition diagram. And look at the composition to the right of the C_1 ; that means, let us call it as C_2 composition, I am just trying to recapitulates, before we go ahead because it is a slightly, you know more difficult concept for you to understand. So, let us try to see if you take up a C_2 composition and a C_2 composition, if I take I can clearly see the liquid of C_2 composition has this free energy, this I would call it as G of liquid of C_2 composition **am I right**. And this, if it has to transformed to alpha of the same composition, it is not possible because G of alpha of

C 2 composition is higher than that of the liquid. So, there is no chance for the liquid to spontaneously **spontaneously**, you may always say transformations are possible from a lower free energy state to a higher free energy state, always, when do they happen, when you somehow energies the lower energy system.

For example, you can one best example is how are X rays generated. X rays are generated, when a high energy beam or a particle hits an atom and knocks off an electron from let us say k shell, which is close to the nucleus and goes out. And this part electron from a k shell going out is going from a low energy to a high energy because it does not want to go out, unless you knock out. So, it is similarly, all excited states that we talk about, are all created from a low energy state to a high energy state by **by** putting in energy into the system. For example, a cold worked state is a high energy state and you have putting cold worked into the material. So, from a low energy state, it has gone to a high energy state. So, everything, so that kind of transformations are not spontaneous transformations, remember so, you have to put in a lot of energy.

Of course, even from a meta stable state to come to a stable state, you need to put in some energy, which is what we call it as activation energy, but though, you have to remember, there is a difference between **there is a difference between** this going to this; that means, transformation in this direction and transformation in this direction. If you see that, this is a meta stable state going to a stable state because this has a higher free energy going to a lower free energy. So, this there is a driving force for it, though there is a driving force, we say there is an activation barrier for it, this is what in the first class itself we have seen. So, but if you want to go from this state to this state, which is a low energy state to a high energy state, the actual energy that it has to scale up is not only this activation energy, but also this **this** free energy difference. So, it will have a much bigger hill that it has to cross, for it to go from here, so it has to climb this and then fall here.

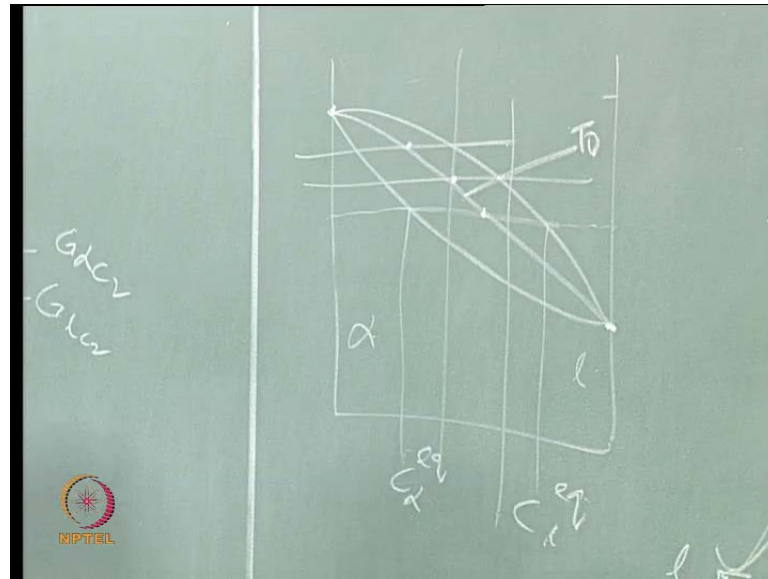
So, if you really want ground state material a phase, **which is** which is a low energy state to take it to the high energy state, you need to provide much more energy. It is not straight away, just giving this much energy is not sufficient, it will not straight away go like that. So, you will see, that is why, it is more difficult for **for** systems, which are in a ground state, which are at a low energy state to be taken actually to a high energy state. Otherwise, you will see that this transformation can regularly occur, that is what we are talking about, whenever we are talking of liquid transforming to alpha, we are talking of

this going to this because at that temperature, we are talking liquid is not stable. So, it is in a meta stable state, but for that also, you need an activation barrier.

And we are saying that, in this case, the activation barrier is, if I now compare something like this, this is liquid of C 1 composition, changing to alpha of C 1 composition, here it is liquid of C 1 composition changing to alpha of C alpha equilibrium composition plus liquid of C liquid equilibrium composition, it is something like this, here the both of them, if you look at it. This is at a high energy state than this, can you see that here, alpha of C 1 composition has a higher energy than the two phase mixture. So, you would but it is lower than the liquid of C 1 composition, so from here, it is going to this, why should it go to this rather than going to this because this is smaller, because that is smaller, why it is smaller because it is short range diffusion **clear**.

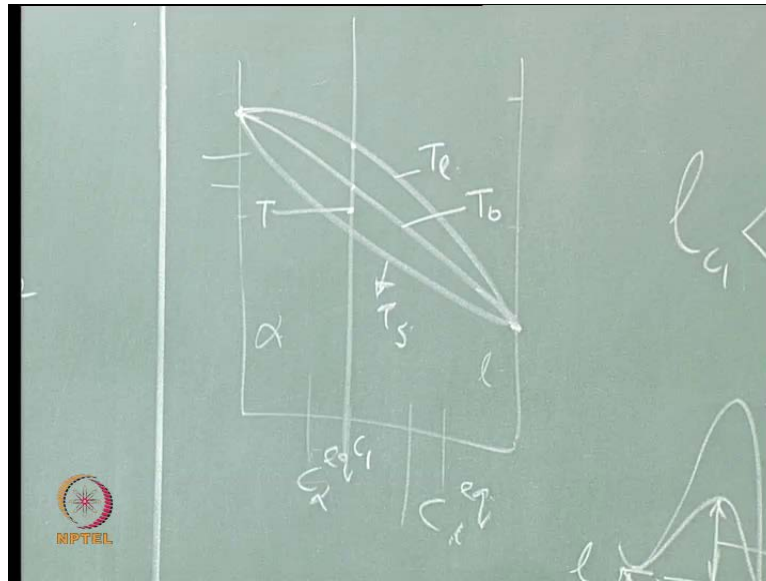
So, you can see that though the driving force is larger and this is a smaller driving force, I call it as delta G 1, I call this as delta G 2, delta G 2 is definitely larger than delta G 1. This, I we call it as path one, call this as path two, for the path one, the driving force is smaller; for the path two, driving force is larger, but activation barrier for the path one is smaller, this is what you can call it as delta G star 1, you call this as delta G star 2. So, the activation energy is larger there because of the large diffusion that is necessary. So, as a result, you would see this is happening in this particular case, where compositions are to the left of the C naught composition, if you are on the right side of the C naught composition than this is ruled out. The first path is ruled out only the choice that is available with the liquid is only second part and that is what happens and what we do is, if we choose compositions at different different temperatures, if you draw this free energy composition diagrams and get these compositions, which are called the C naught compositions.

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For example, if I draw free energy composition diagram at some other temperature like this, I can get another composition, which will be again between these two points. If I draw at some other temperature, I will again get one more composition, which is between those two points like that, if I get and join all of them, I will get a line like this. And incidentally, this line would meet with pure metal melting point here and again meet with pure metal melting point on this side, why, because those two points are where, the definition of a pure metal melting point is what? What is the definition of a melting point? Free energy of both the phases the liquid and the solid is equal. And we are talking of C naught is nothing but the where the free energy is equal, free energy of liquid and solid is equal. So; obviously, this particular composition or this particular temperature, we now call it as a T naught, this curve is call T naught curve. So, if you choose this I will erase this and then redraw for use to reduce the number of lines.

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Though in isomorphism this is not very useful concept, you will see as you go to eutectic this becomes very useful. For example, if I now take an alloy composition called C 1, what is this line the top line?

(C)

Liquidous very good, So, this is called T l, T liquiduos the bottom is solidus T s and this called T naught, T naught is T 0, the naught means 0. So, why we say 0 because there the delta G is 0, delta G for the transformation is 0, that is why, we call it as a T naught curve and this T naught curve, what is the significance of it now. The significance is this, if I take any alloy and I under cool this liquid make it **make it** completely liquid and then I am cooling this liquid, but if I under cool the liquid to a temperature, below the T naught. Let us say, I bring to this temperature, there is a difference between bringing a liquid to that temperature and under cooling the liquid to that temperature. I repeat this, there is a difference between bringing the liquid of C 1 to this temperature and you call it as, let say T or under cooling the same liquid to temperature T, what is the difference between the two. It is not the cooling rate.

(C)

I am saying that, I have under cooled C 1 to temperature T, I am also saying I am cooled liquid C 1 to temperature T, what is the difference between cooling the liquid to C 1 temperature, what is the temperature between...

(())

Yes, when I say under cool the liquid to C 1, T T temperature; that means, until you reached T, the liquid remained as liquid, it did not transform. Otherwise in principle, when you are cooling this alloy, the solid should start forming here, under equilibrium conditions. If it is normally cooled, by the time you reach this temperature T already some solid should have form and some some liquid is left out. So, if you simply are saying that, I am cooling the liquid to T temperatures T, it means solidification has started, but the moment you use this term under cooled. It has a special significance; that means, until you reached that temperature, nothing has happened to the liquid, just only the temperature has come down, liquid remained as liquid, when does this happen? It happens only when there is non equilibrium solidification. Under equilibrium this will not happen, only under non equilibrium condition; that means, I have cooled it rapidly or there are also other conditions. Do you know, what is the other condition by which you can under cool the liquid, in fact in ninety fifties, there is a great man by the name Turn bell, who did special experiments to see, how he can under cool the liquid, anybody has heard of it.

(())

Yes anybody (No audio from 19:14 to 19:18) no, there are called droplet emulsion technique (No audio from 19:22 to 19:31) can you have heard of that word, droplet emulsion technique anytime no, what he said is most of the time, the nucleation occurs by, what is called heterogeneous nucleation is not it. All of us know, most of the time, in fact, if you want homogenous nucleation is very very difficult, that is why people are doing, what is called... You know drop tube experiments, peoples are also doing, what is called levitation experiments, what is called container less solidification. Have you heard of container less solidification? If you want to see containers less solidification, go to Professor Pazhani Kumar's lab, you can actual see it happen. So, how to do container less solidification, levitate a liquid droplet and allow it to solidify. So, that it floats in the

air and then solidifies, so that you can see possibly there is no mold effect. So, solidification has to start may be at the surface of the liquid or within the liquid.

So, what Turnbull has started is, most of the time liquids always have some inclusions inside them and these inclusions can act as nucleating sites, these are what we call foreign bodies some think like that. So, he says if I can somehow reduce these foreign particles by making the liquid droplets smaller and smaller. The probability of finding a foreign particle reduces, if you make drop liquid into smaller particles. So, he did some kind of an atomization of the liquid droplets, so when the liquid comes out of a nozzle it tries to basically put a gas, so that it forms the whole liquid into the form of a jet stream.

And then the different sizes of particles are formed and he very painstakingly took each particle of the solid that has formed. And then polished each particle may be embedded each particle into something and then polished it. To look at the micro structure of this particle in the cross section and when he looked at different sizes of particles, he saw that the smaller the size of the particle the finer the micro structure, whether it is the eutectic lamellar spacing that he is talking about or the grain size that he is talking about, he saw that the finer the smaller the particle is finer, that basically means the nucleation rate of that is higher. And that he calculated back and said this is happening because you have a larger driving force, where from the larger driving force has come, because the liquid got cool to a lower temperature; that means, liquid got under cooled to a higher and higher under cooling.

So and people have later with various techniques confirmed that, yes this is what has happened and so now, people actually do this droplet emulsion very regularly whenever you want to study this, what is called **what is called** nucleation experiments, under cooling experiments. One of the most popular techniques of under cooling experiments is this. So, one way is to cool fast, here there is no fast cooling in the **in the** droplet emulsion the cooling rate is normal, but you have deliberately made the particle smaller. So that, the foreign particles reduce and if there is no heterogeneous nucleation, the liquid has to keep on under cooling until a particular temperature called homogeneous nucleation temperature. You all must have gone through nucleation kinetics somewhere. So, in the nucleation kinetics we defined something as T_N , nucleation temperature homogeneous nucleation temperature, how do you get that homogeneous nucleation temperature, anybody knows.

(())

How do you calculate that, all of you in second year B tech should have heard this, if not go back to (()) today and read read him, nucleation chapter in read him, I will not going to the details because, we are taking of thermodynamics, I do not want to go deeper into the kinetics, I can take one extra class on that, right now, but I want to avoid. So, that you read a little. So go back and read a (()) way to called calculate, what is called homogenous nucleation temperature, which people called it as ΔT_N , under cooling required for the homogenous nucleation. So, if heterogeneous...

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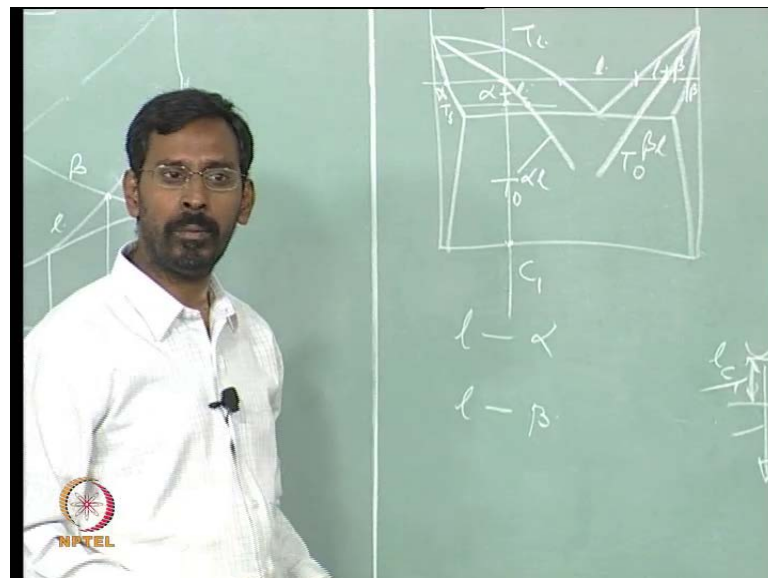
Yeah basically form Turn bulls, you can come, of course everything has come from Turn bull, Turn bull is the father of under cooling. So, anything that you talk of under cooling of liquid, you have to start with Turn bull because turn bull who's started. So, basically try to see, what that barrier for nucleation and how to overcome that barrier, what is a barrier for nucleation surface energy. So, you need to provide sufficient driving force to overcome that surface energy and from that driving force, you calculate that ΔT . We will come to it possibly after these; I tell you how to calculate that ΔT . So, we will see that so basically you are to (()) get that ΔG , once you calculate that ΔG form the ΔG , will get ΔT , so coming back here. So, if you are at this temperature because you are below the T_{naught} , what does it mean by below T_{naught} , if I draw a tie line at that temperature if I draw a tie line at that temperature, my compositions that I am choosing is to the left of T_{naught} curve am I right; that means, partition less solidification is possible. If I take the same alloy under cool this alloy to this temperature, I called it as T_1 , let us call this as T_2 . At that temperature; that means, this the under cooling of this alloy is smaller now, this is I can call this as ΔT_1 , this is ΔT_1 and this is ΔT_2 .

So, I have given a smaller under cooling and at that temperature now again, if I draw a tie line, I see that my alloy composition now, is to the right of the T_{naught} corresponding to that, at that temperature my C_{naught} compositions is to the left, of my alloy compositions, if I am on the right side of the C_{naught} compositions. I have already seen here that there is no driving force for partition less solidifications, only if I am on the left side of the C_{naught} compositions, at any given temperature, there is a driving

force for the partition less solidification. So; that means what effectively saying that, if I can bring an alloy below that T naught curve, for any alloy composition there is a T naught point. If I take these alloy, for this alloy this is the T naught, if I can come below the T naught, if I can under cool my liquid below that T naught then there is a possibility for partition less solidification, if I cannot under cool my liquid below T naught, for whatever may be the reason, all those droplet emulsions, wherever the droplet has under cooled below the T naught.

You would see a spontaneous nucleation everywhere, otherwise it has to wait for the surface to nucleate and the nucleation will go involves, in fact the way, the nucleation has happened also you will know, whether it is a heterogeneous nucleation are nucleated on a particular foreign particle somewhere inside or it has nucleated everywhere and then started growing and that is what, you would see, if you have below the T naught. So that is the significant of being below T naught or being above T naught. So, you can say that, if I can bring the alloy below the T naught then I can have partition less solidification, if I am above the T naught then there is no partition less solidifications.

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And this becomes more important, when we come to eutectics; let us just look at a eutectic phase diagram. (No audio from 28:00 to 28:08) Let us look at a eutectic phase diagram (No audio from 28:10 to 28:18) and now, if it is a eutectic phase diagram, I will have not simple one T naught curve, I will have two T naught curves, why, because I

will have one T naught curve between liquid and alpha, I will have another between liquid and beta. In fact, I can even talk about another between alpha and beta, we will not talk right now, because these of not that much significant, because we are talking of solidifications. So, what is the first one? The first one is let us look at, this curve and this curve, what is this curve? It is liquidous T l, what is this curve? This one, solidous T s, so if I draw line there, some temperature there and then extrapolate that, to that, now, if I want to draw a free energy composition diagram at that temperature, how will it look like.

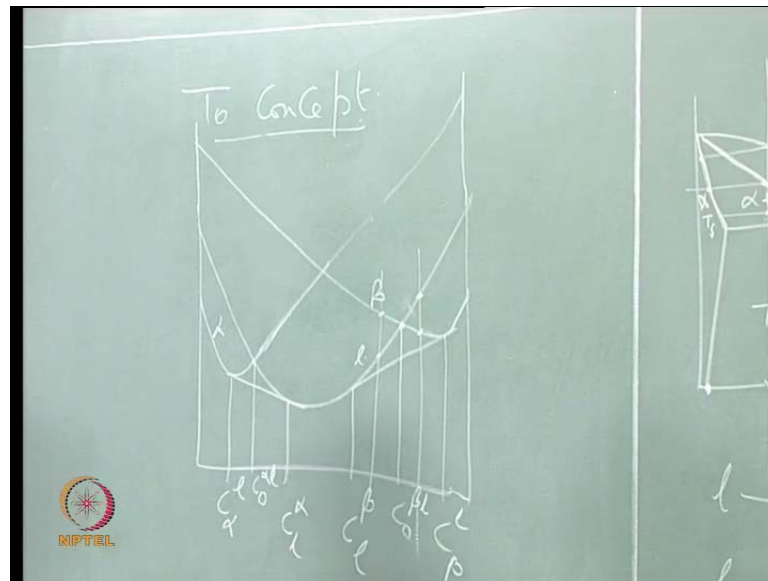
(No audio from 29:17 to 29:23)

It will be similar to what I have drawn before, but with some additions, what is a addition here, we will have one more additional curve, instead of two curves, I have to now draw three curves. And incidentally, because liquid is here and before we even draw that, let us identify the phases **phase** fields here. If I draw that tie line there and this tie line tells me that, wherever it is intersecting the phase boundaries, it defines certain phase boundaries, certain domains for phases. For example, this one, this tells me that to the left of that, I have single phase alpha is not it. Between these two, I have alpha plus liquid; this is alpha alpha plus liquid and between these two, what do I have, I have a liquid, so and I have here.

(O)

Liquid plus beta and I have here beta **am I right**. This is known to all of you, **fine**. So, if that is the case then when I am drawing the free energy composition diagram a schematic one then liquid should come somewhere in the middle **am I right**, alpha should be on one side; beta should on the other side.

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Now, let us draw that, so I have a liquid curve, of course I need not have to draw like this, I can even because liquid extents, I have a liquid curve like this, I have an alpha curve; I have a beta curve. Of course, you may say sir, why are you closing here? This fellow will go and somewhere hit here and similarly, this fellow also will go and hits somewhere (No audio from 31:11 to 31:20) **fine**. I have three free energy curves, I will call this as a liquid; I will call this as a alpha; I will call this as a beta. Now, you will have not just one single common tangent, you will have two and in fact one can also talk about the third one, let us not talk about it right now. This is a one common tangent, the other common tangent is this, so you can talk about two compositions here and two compositions here, what is this composition?

(C)

Yes this is C alpha I perfect, what is this composition, C I alpha composition of liquid in equilibrium with alpha, what is this?

(C)

C1

(C)

Beta and this is

(())

C beta l, perfect you are all getting it right. So now, once I know this, again I have two T naught, two C naught here, this is C naught for alpha liquid; this is C naught for beta liquid **am I right**. I will have one for the alpha and liquid, I will have one for the beta and the liquid. So; that means, on this temperature line, I can put two points here, one point between the alpha and liquid; one point between the beta and liquid. And this liquidous mind you, there are two liquidous here, carefully see, this is one liquidous, this also a liquidous, this is what we call it as alpha liquidous; this is what we call it as beta liquidous. Similarly, this is alpha solidous; this is beta solidous, just to differentiate because between that, on this side. It is liquid in equilibrium with alpha and this side, it is liquid in equilibrium with beta, just the terminologies, I want (()) know.

Now, if I continue this at various temperatures, I can keep on drawing similar curves, at different **different** temperatures and at each temperature, I can get one C naught alpha liquid; one C naught beta liquid and if I join all of them, I get line like this, two lines, one I call it as T naught alpha liquid, another is called T naught beta liquid. These two are very **very very** important concepts, when you are talking about non equilibrium solidifications. The whole micro structure development in non equilibrium solidifications just depends on this concept, so please try to understand this. So now, if I take this, if this is the T naught, this is a calculated value based on the free energy concepts, whereas this whole phase diagram other than this two T naught curves, you do not need the free energy calculations to get that, how can you get the whole phase diagram, without free energy by thermal analysis, by doing thermal analysis one can get the **the** phase diagram, but by doing thermal analysis, you will not get the T naught curves. T naught curves alone are fully a free energy concept, so T naught curves can be obtained only if you have a free energy equation.

So, you need to have a G alpha equation, you need to have G liquid equation and G beta equation and from that, find out at various temperatures, where are the free energies, equal finding out the intersections. So, basically equate G l with G alpha, G l with G beta at a particular temperature and then find out where these two are equal, which compositions of liquid and solid, where you have this equal and that if you can calculate you will get this. So, these are the actually calculated, you may also calculate the phase diagram, I do not say no, the whole phase diagram can be calculated from free **free**

energy, but the whole phase diagram in a large number of cases can also be obtained experimentally, by doing thermal analysis, but by doing thermal analysis or any other experiment you will not be able to get this, this has to be calculated from free energies.

Of course, you possibly need some experimental data to get the free energy, what is the experimental data that you need, C_p and one more for a solid solution you need one more data.

Omega.

Omega **omega** is ΔH_{mixing} , so ΔH_{mixing} also comes from experiments; that means, when I take a and b, whether this a and b they have **they have** an attractive interaction or repulsive interaction, how much is that interaction, again can be obtained from the calorimetric, that is calorimetric. So, for example, for this most of the time, you do not use a ΔS_{mixing} would be sufficient, if I if you want liquidous and solidous liquidous and solidous even a ΔT is sufficient are in a simple thermal analysis can be sufficient depends on of course, how shallow or how deep it is, So but here, the any free energy calculations, what you need is C_p data and ΔH data, these two data are required. If you want really calculate the free energy for anything, if you have these two data available, you can always calculate.

And now, if I have this, now how do I understand this. So, again the same thing, if I say, if I take an alloy of this composition, let us use an alloy of that composition. This alloy the moment I cool it below, again cool it undercool it, if I under cool it below this temperature to some temperature like this, any temperature of that sort then at that temperature if I look at it, this is to the left of the T_{naught} or the C_{naught} corresponding to that temperature, you have to be very crisp, when you start defining technically. So, this composition is to the left of the C_{naught} composition for that particular temperature. For that temperature this is the C_{naught} , this whole curve is called T_{naught} because why, because this is giving the locus of all temperatures or locus of all compositions at various temperatures, where the free energies are equal, locus of all composition at various temperature, where the free energy are equal that is what is the meaning of T_{naught} curve.

So, now because we are on the left side then I can see partition less solidification can occur, what does it mean; that means, liquid having this compositions, whatever

composition it is C 1, would simply become alpha of C 1 whereas, this particular alloy under normal conditions, what it would suppose to happen, when I am starting cooling this alloy, the moment you reach this temperature, it should start forming alpha having this composition, you all remember. So, the moment I reach here you have to draw a tie line there where it hits, that will tell you the alpha composition that is going to come out of the liquid. And then as you slowly come to lower and lower temperature, by the time you reach eutectic, you will have more and more alpha and at the eutectic whatever the liquid that is left out is, will undergo a eutectic reaction.

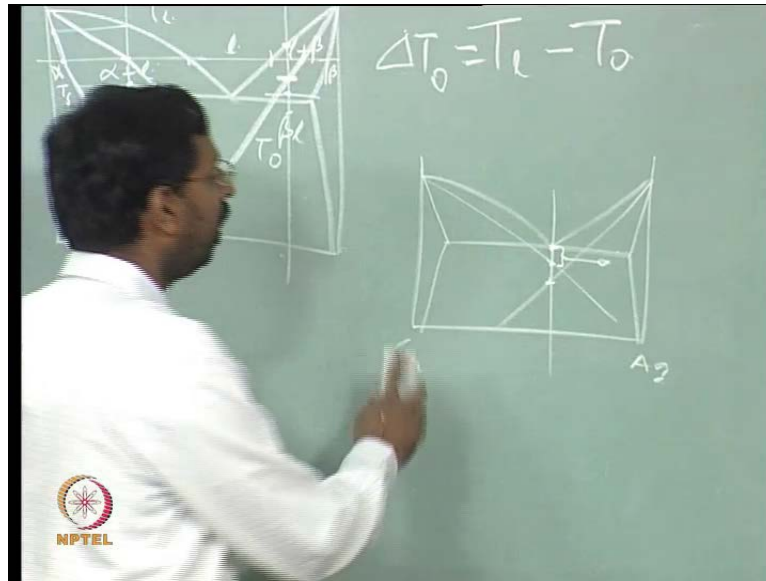
And in this alloy, once I reach the room temperature, you will have primary alpha plus a eutectic mixture. This is the typical micro structure for that particular alloy, which we usually call it as a hypoeutectic alloy **am I right**, whereas now, this same alloy when I cool it rapidly, to an under cooling of that sort, I do not have any eutectic, nothing I will have singly simply as single phase alpha at room temperature, with the same composition as that of the liquid, what does that mean; that means, I have a moment I reach this temperature, at this temperature I have instead of two phase mixture alpha plus beta, I have single phase alloy of simple alpha and what does that mean; that means, that I have now got a super saturated solid solution.

Actually in principle, at room temperature alpha can contain only this much of b this **this** is what defines a solubility limit, this is the beta b amount that can there in alpha, but now I have an alpha, which has this much of b, so single phase alpha, that is why, you know T naught concept become very important, that you can completely change the way solidification occurs. If you can really under cool an alloy below the T naught, you can have solid the solidification taking place in such a way that instead of normal regular eutectic solidification, primary phase and eutectic mixture, you would simply have, what is called a **what is called a** single phase partition less solidified alpha.

And on this side, if you have, for example, if I take this alloy, now under cool it to this temperature, at this temperature whatever it is, even if you under cool to this temperature let us say. Now, I am here, I have to consider the other way, here I am on the right side of the T naught C naught, so; that means, where I am on this side, I am on the right side, what is the meaning of right side. Now you see, the liquid has a higher free energy than the beta, why I am talking of alpha and beta, the right and left get inversed is not it. So, on this side, you would see liquid has a higher free energy than beta. So, partition less

solidification is possible, if I you are on the right side of the C naught, if I am on the left side of the C naught beta have a higher free energy than liquid. So, partition less solidification is not possible. So; that means, again whether you are right or left, one thing is true, if I am below the T naught, if I under cool my liquid below the T naught, that is why we always this can be confusing this cannot be confusing.

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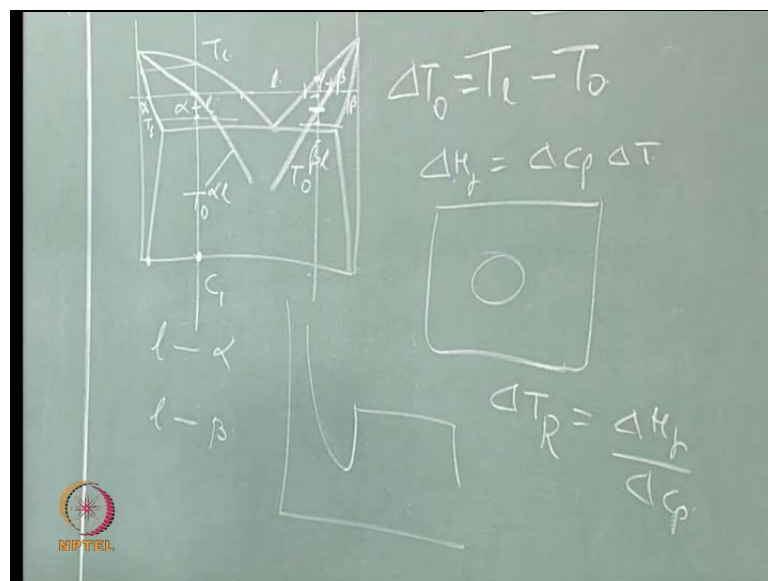
So, if I can under cool my liquid, what is the under cooling that need to give, I should give a minimum under cooling of T_l minus T_{naught} , this is the under cooling that I need to provide, for a given alloy composition. If I can calculate, what is the T_{naught} and if I know what is that T_l for that particular alloy, now the difference between this; that means, this minus this, will give me what is the minimum under cooling that I should provide, if you give only exactly that, it is not sufficient because you need some driving force because, if you are exactly there at the T_{naught} , free energies are equal **free energies are equal** does not mean that reaction will happen, you have to be slightly below the T_{naught} . So that, the liquid has the higher free energy then the alpha, of the same composition then you would see that this. So, this is the minimum ΔT_{naught} that you should give, that is where we see that, if you go deeper this is also not sufficient, what is the problem? The problem is this, is this clear now, so this is what is the whole T

naught concept and this T naught concept can give you, how to get extended solid solutions, these are what are called extended solid solution.

One of the basic advantages of rapid solidification processing, which Pol Dewey, I mention to you in 1959 has discovered is this. For example, what he has done, he has simple taken a copper silver phase diagram, (No audio from 44:13 to 44:19) copper silver and he took a eutectic alloy and cooled it rapidly, when he cooled it rapidly, he found that this eutectic alloy will give only a single phase structure rather than a two phase structure. It is supposed to give a two phase alpha plus beta whereas, you got a single phase structure, that is because, he has under cool to an extent, that if I draw this, whatever it is, if you have under cool there are other further questions that may come in to your mind, we will address those thing also sir, what could happen if under cool below this or below this. So those questions also we will try to answer as we will go along.

So, if I under cool below this or below this, I would get either single phase alpha or single phase beta. So, I can in principle get a single phase structure, just by under cooling it, what I should know do is, if this is the liquidous temperature and if this is the T naught, what I need to provide is this much of under cooling; that means, my cooling rate should such that, it gives that much under cooling, if at get that much under cooling than in principle, I can get partition less solidification a eutectic alloy gets converted to almost like a isomorphous alloy.

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So this is what we call it as meta stable phase diagrams. So, eutectic vanishes completely, when you do a rapid solidification, but there is a small other additional problem. What is the additional problem? The additional is this. The moment you take a liquid in which a partition less solidified alpha has nucleated, what happens then? The moment alpha gets nucleated, there is a heat release **am I right**, what do we call this?

(())

Latent heat release, we called this with a particular term, what is this called, this latent heat release is called something

(())

Heat of fusion is the same, the process **the process** is process of a latent heat release is called something, it is called recalescence add of it **yes no yes** I heard both, it is called recalescence, this is nothing but heat release, when a liquid becomes a solid, why because the solid is not able to contain all the heat which is their inside the liquid. So, the moment this particular area, this particular volume gets converted in to liquid into solid then immediately, that particular volume releases some heat, because the earlier this volume had all liquid and it had a high enthalpy. Now, it has got converted to a solid, which can contain only a low enthalpy. So, there balances enthalpy is released, where is it released, it is released into the liquid which is surrounding it, is not it, that is why the moment you see a solid forming, there is a increase in the temperature, that is what if you remember, all you, all the moment nucleation occurs.

You have a recalescence, on the moment you have a recalescence than if I say, I have under cooled the liquid to this temperature let us say and if the recalescence will raise the temperature or the liquid above that of the T_{naught} then you are in soup, you are in liquid, not in soup **soup** liquid is also a soup. So, you are in to the liquid back again. So, you cannot that means, you are in at a temperature somewhere like this let us say, where partition less solidification cannot occur. So, the remaining liquid cannot continue to do partition less solidification. So, you are in trouble, so that is why, people now call that the minimum under cooling that you need to give is not just this, this plus something, how do I get that plus something, that plus something can be obtain.

Simply, if I know, what is the amount of enthalpy that is released, so if I know that, ΔH_f is nothing but, $\Delta C_p \Delta T$, if I can put this, **am I right**. In principle, I can put that, so, H is $C_p \Delta T$. So, similarly ΔH_f , where which is nothing but, the difference between H of liquid and H of solid can be taken as difference between C_p of liquid, C_p solid and into the ΔT . So, if this much heat is released and if this is the ΔC_p difference between the two liquid and solid, this will be the under cooling, this will be the temperature rise not under cooling, temperature rise because of the heat of fusion. So, if I know this **this** value, I can calculate ΔT recalescence, I call it as ΔT recalescence as nothing ΔH_f minus ΔC_p not minus divided by **divided by** ΔC_p . So, if I know the ΔC_p , that is where the whole problem comes after the moment, we complete this, we are going to a another concept possibly tomorrow, where you will see what is the problem with this ΔC_p , there is the major problem the whole another new field of whole thermodynamic as evolved, just because ΔC_p problem, tomorrow I will address that.

So, you see that this ΔT_R can be calculated, so the actual ΔT that you need to have is ΔT_{naught} plus ΔT_R , this is what is called hyper cooling concept. This concept is called hyper cooling, so this is the **...** if you can give this much of under cooling, then there is a no problem at all, because it takes care of even the recalescence also, so you are not simply cooling up to just up to this, but to a temperature here. So that the recalescence, even after recalescence the temperature does not cross that, so you basically heat it to such a I mean under cool it to such a temperature, that even after recalescence the temperature does not cross the T_{naught} . And that is what is what we call hyper cooling concept, we will talk more about it as we go along, **thank you.**