Advanced Metallurgical Thermodynamics

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Module No.01

Lecture No. 14

Peritectic Solidification, Metastable phase Diagram

We have been sofar seeing the free energy concepts utilized in solidification particularly, during the liquid to solid transformation. We looked at various aspects such as how phase diagrams evolve, particularly looking at liquid and solid. We also saw how the isomorphous solidification takes place, how free energy composition diagrams evolve as a function of temperature in the isomorphous.

And, we also introduceda concept called t naught, which was again related to liquid and solid. And then, we extended that T naught to Eutectic. And then,we saw what are the kinds of information that we get, particularly looking at glass formation and also extension of solid solubility.And, we also saw in the last class particularly on, how the Eutectic solidifies? Particularly, the coupled growth of the alpha plus beta, how do alpha plus beta together growin a liquid matrix?Howdoes the liquid supply atoms to alpha and beta?

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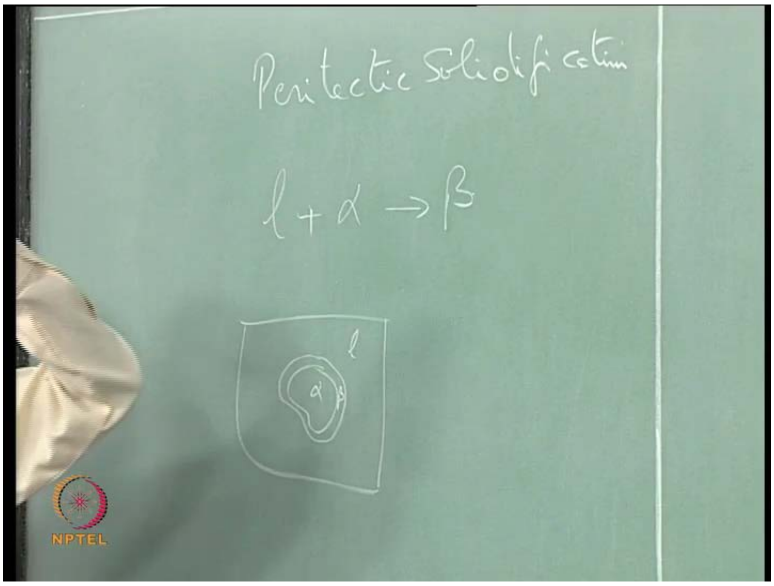

Let us look at Peritectic today. Peritectic solidification is a very interesting solidification process, where, if you remember, what is the Peritectic?Liquid plus solid one,gives you second solid.That is what is the Peritectic.

So, l plus alpha gives you a beta. This is what is the Peritectic reaction.And, if you look at this Peritectic reaction, if you imagine that there is a liquid,inside which there is an alpha.And, this liquid is reacting with this alpha and beta is coming out. Where should this beta come out?Where will it nucleate? When, beta comes out of the reaction between the liquid and alpha, where should this beta come? It should be at the interface. Is not it. So, in principle, you will have the beta forming at the interface as a thin layer. This is what is beta. The moment, you have a beta form at the interface between liquid and alpha, there is no more interface between liquid and alpha.

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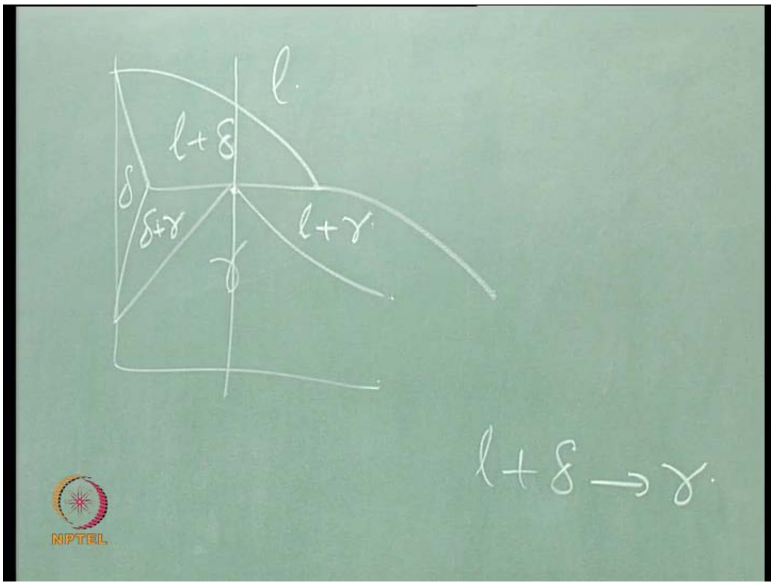

So, how does this Peritectic reaction continue? Because Peritectic reaction is liquid plus alpha, giving you beta. And, the moment, the initial reaction starts at the Peritectic temperature;let us remember our Peritectic phase diagram.This is a typical Peritectic.Many of you should know this because it is a part of the Iron-Carbon diagram, which all of you aware of. So, let us use exactly the Iron-Carbon itselffor understanding. In Iron-Carbon, what is the reaction, Peritectic reaction in Iron-Carbon?Liquid plusdelta gives you gamma. So, it is liquid plus delta gives you gamma.

So, where arethephases then? This is the liquid; where is delta?Delta is on the left side here; and where is gamma? Gamma is the outcome of the reaction. So, gamma should be at the bottom. Is not it. So, that meansthis is liquid plus delta; this is delta plus gamma and this is liquid plus gamma. Am Iright. And, at this temperature,at this Peritectic temperature, if I take a liquid and cool it to a temperature just below the Peritectic,the moment the liquid starts solidifying, it gives out delta. It is this portion of the phase diagram. Initially, delta comes out of liquid and that is how you see delta inside the liquid. And, as you continue solidification to lower and lower temperature, more and more delta comes out. Is not it. And, we can find out the volume fractions of this; not the really the volume fractions,the weight fractions because the phase diagram does not give you volume fractions. I thinkthis, you must be aware of by now.

Phase diagram cannot talk about volume fraction because phase diagram,the x-axis is basically, a weight fraction of x or atomic fraction of x. So, volume does not come into picture. Though, how do you get then the volume fraction of a phase?We can get byusing the density. If I know the densityand if I do the microscopy, what is that I will get?For example, if I have a two phase mixture and I do a microscopy, what is that fraction that I get?Volume fraction?You get actually the area fraction. Because you are seeing two dimensionsections, you are actually not seeing a three dimension. So, any microscopywill only give you the area fraction. And, again from the area fraction,you need to convert it to volume fraction.Again, certain assumptions; there are ways to convert.There is a book called "Quantitative Metallography".If you are interested, you please read that.

So, where they talk about, how to convert area fractions to volume fractions?Certain assumptions,of course are involved. If you assume it to bespherical particles, then it is easy toconvert area fraction to volume fraction. Otherwise, it is very difficult.For example, you think of a plate of a second phase in a matrix. And, if you cut the plate like this, then what you see? You see it as a needle. Is not it. We are not actually seeing a plate; you see it actually as a needle. So, this needle area that you are seeing, if you want to convert into volume fraction of the particular second phase,it is not soeasy. If it is spherical particle, it is easy because whenever, you cut it, you basically get circles.Depending on, where you cut it, you get different diameters of the circles. So, that is why, all conversions of area fraction to volume fractions are much easier, if you have spherical particles.

But, in the real life, you do not see spherical particles all the time. So, that is why, one need to do some geometric approximations and people regularly do it.There are mathematical ways of doing all this. So, you should remember that, our microscopy always gives you area of fraction and our phase diagram always gives you weight fraction.And so, the moment you reach this temperature, you have basically liquid plus delta of certain amount of liquid, certain amount of delta, depending on that particular phase diagram. Which can be easily found out by what?How do you find out the weight fractions in a phase diagram? Lever rule.

So, you use the Lever rule and from the Lever rule, one can find out. Now, this plus liquid plus solid, liquid plus delta is undergoing a reaction and giving you gamma because I am at that temperature, just below the Peritectic.Now, what should happen in a Peritectic reaction? Liquid plus delta should completely vanish at the end of the Peritectic reaction and only gamma should be left out.That iswhatis the Peritectic reaction.But,what we are seeing hereis, the moment there is a reaction, the gamma that forms here, I will write asgamma here, for the sake of that particular case. So, this is what it is.

So, liquid plus delta giving you a gamma, the gamma that comes out covers the whole of delta because that is where the reaction is occurring. So, the moment the delta is completely covered, there is no possibility ofhaving this further reaction between liquid and delta to take place, sothat liquid slowly shrinks and delta also slowly should shrink such that, the gamma should encompass both the liquid and the delta. And, for that to happen, you need the reaction to continue. How does the reaction can continue, when there is no interface at all, available between delta and gamma, delta and liquid.

This whole problem of Peritectic is what actually leads you to cases where, Peritectic reactions are very slow.That is why sometimes you may, if you cool this steel faster, you may even end up in some delta left out at the end ofsolidification because the reaction, Peritectic reaction has not actually gone to completion. There are certain phase diagrams, which are full of Peritectics.Do you remember any such phase diagram? We usually use a term called“Cascade ofPeritectics”.You have gone too far off, I do not know about this Uranium.But,something whichmetallurgists are commonly aware of, which is the very important system for commercially Copper zinc, Copper Tin. There are lots of Peritectics.

In fact, the system has onlyPeritectic;Copper Zinc; if you look at it.It has nothing else in the liquid to solid phase transformation.Of course, in the solid state you may have something else, but in the liquid to solid, you have variety ofthe various inter metallic that you see; beta phase, gamma phase, epsilon phase. All these phases come out of the Peritectic reaction and because of that, you will see many of this reaction are very slow. Now, try to understand howthis reaction proceeds.To understand that, again let us use our free energy concept. Yet,at this temperature, I amsorry it is not horizontal. At this temperature, if I draw the free energy composition diagram;all of you try to draw it.Letus see how it should look like.What you have?You have a delta here; you have liquid plus gamma, gammaand liquid plus gamma.

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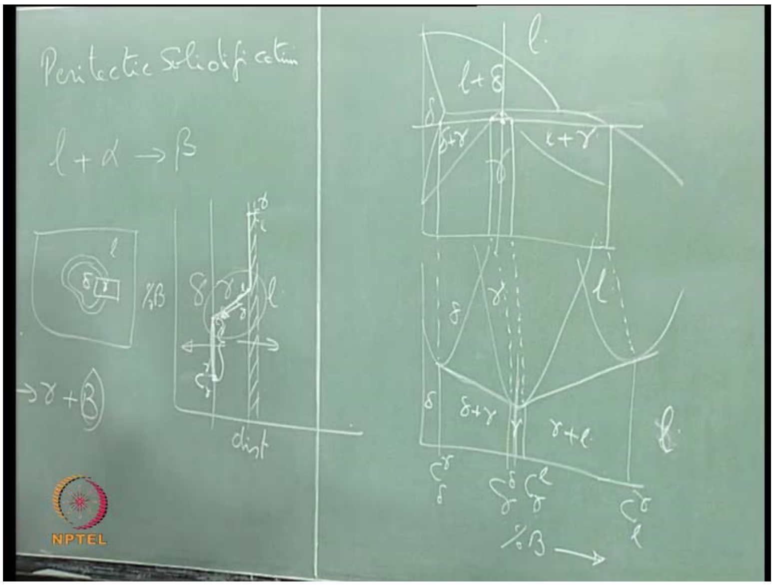

How many phases are involved in this?Four phases.How many phases are there at that temperature? If I want to draw a free energy composition diagram, I need to know, how many phases are there? There are three phases. What are the three phases? They areliquid, delta and gamma. So, let us try to draw. So, there is a delta, there is a liquid, there is a gamma.Is not it. So, in principle, you have a delta plus gamma equilibrium.You have liquid plus gamma equilibrium. So, this is the delta phase, this is the gamma phase, this is the liquid phase. And, this composition, that I am getting are what?This is the composition of delta in equilibrium with gamma.

So, I can say that, this is composition of delta in equilibrium with gamma. This is composition of gamma in equilibrium with delta.Am I right? And, this is the equilibrium of gamma and liquid. So, this is the composition of gamma in equilibrium with liquid and this is the composition of liquid in equilibrium with gamma. And, where do you see them on the phase diagram? You will see it exactly here, this one; this point is nothing but,the composition of delta in equilibrium with gamma. So, this is actually, this composition. And, this composition is the composition of gamma in equilibrium with delta; that means, in principle, it is that composition.

And, this composition is nothing but the composition of liquid. I mean, gamma in equilibrium with liquid because this is the gamma phase. So, that composition is in principle, this composition. And, then you get another composition, which is the composition of liquid because everything is liquid on this side; it is the composition of liquid in equilibrium with gamma and that turns out to be nothing but this.If you draw everything to scale, you would exactly get this compositions reflected there. I have not drawn to scale.That is whyIneed to do this.

So, you can see that these four compositions,that is why, whenever you draw a free energy composition diagram, it should completely reflect the phase diagram.This has to be, at least at the end of this course,it should be very clear to you. So, nowif I get these things, how do you understand this?How is it useful for us to understand the PeritecticReaction?

What you see here is, if I now drawa small segment of this, take a finite element from this and try to look at it. What you have is you have a delta. If I drawsomething likedistance,as the function of distance, you have delta phase, you have a gamma phase and you have a liquid phase. Am I right? So, liquid and delta are separated by a gamma. And now, if I look at what is the percentage of B; that meanscomposition of each of these phases, if I try to look at, how do they look like?

For example, there are two interfaces here.One is a delta/gamma interface; one is gamma/liquid interface.At each of the interface, there are two phases, which are in equilibrium.At this interface, delta and gamma are in equilibrium.At this interface, gamma and liquid are in equilibrium.If I look at this equilibrium first, delta and gamma equilibrium,I need to look at what is the composition of delta in equilibrium with gamma and what is the composition of gamma in equilibrium with delta. If I look at that, I get those compositions from here.

So, if I look at those compositions, composition of delta in equilibrium with gamma and composition of gamma in equilibrium with delta, this is an increase in percentage B. Am I right.So, that means, the composition of gamma in equilibrium with delta is higher than the composition of delta in equilibrium with gamma, in terms of percentage B. Am I right. So, in such a case, I can put these two compositions somewhere here.One, I will call it as composition of delta in equilibrium with gamma, composition of gamma in equilibrium with delta.Whatever the scale that you choose,I am just schematically drawing them.

Now, if I look at the other interface, which is the gammaliquid interface, I get two other compositions. One is, the composition of gamma in equilibrium with liquid, another is the composition of liquid in equilibrium with gamma.And, those two compositions and if you carefully look at it, the composition of gamma in equilibrium with liquid is higher in B content than the composition of the gamma in equilibrium with delta. Am I right? So, as a result, this composition C gamma liquid is going to be higher than this value. And then, the next one is further higher. So, I can call this as C gamma liquid. I will call this as C liquid gamma. Now, if I do thiskind of a profile, I can see the composition profile is something like this.

I really do not know, whether this iscontinuous horizontal into this. Let us not bother about it. In principle, it may not.Why? If you carefully observe,what is the composition of liquid with which we have started? We have started with a Peritectic composition. At the Peritectic temperature, what is the composition of theliquid? It is decided by the Peritectic horizontal. At the Peritectic horizontal tells me that, this is the composition of liquid, which is reacting with thisdelta and giving you this gamma.Am I right?So, that means, this is the composition of liquid;in principle,which is actually reacting with alpha. And, at this delta, at this temperature, the composition of actual liquid is this. And, that is different from the liquid, which is actually interacting with that.

If you want to have equilibrium between that, you should think of that. So, in principle, this liquid composition throughout may be exactly that or might fall that far from equilibrium,far from this interface, the liquid composition may be this composition. If you have a very slow cooling conditions that you will see all the liquid will have the same composition as that of this.This is what is we called it as equilibrium.

If not, you may see… that is why we talk about coring. So, if there is no equilibrium,then you will see the liquid composition at the interface will be this, but far away from the interface will be this. But,otherwise you can assume to be that. But,we are not bothered about that particular part more. What we are bothered about is, here. We are saying that if Peritectic reaction has to happen, what should happen? If Peritectic reaction has to complete, then what should happen? This gamma should grow like this.Should grow in this direction and in this directionsuch that, it observesall the delta. It also, observes all the liquid.That iswhen we can say Peritectic reaction is complete. So,that means the gamma should grow in both the directions. And, how does this grow? We are saying that, there is no interface between liquid and delta left out. If there is no interface between liquid and delta for the gamma to grow, the only way is by diffusion of atoms. How does this happen?

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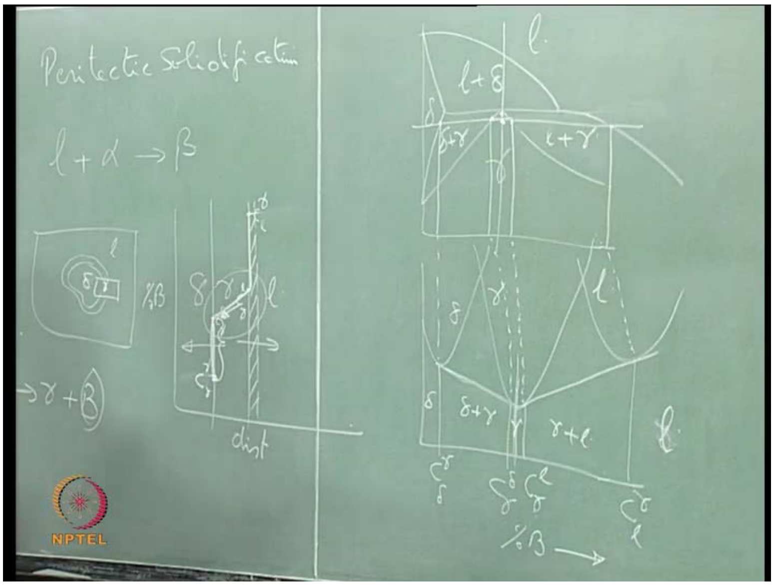

To understand this, we look at each of the interface.For example, if I look at the interface of liquid/gamma interface; at the liquid/gamma interface, if I look at it, liquid has higher B content than the gamma. So, what happens is, in order to, for the Peritectic transformation to complete.

Because why this has to happen because at that temperatures, for that alloy composition liquid is not stable.Isnot it. If I am at this temperature, at this temperature, for that alloycomposition, with which I have started with.What is stable is, only gamma. Thermodynamically,that I can clearly see here. My alloy composition is somewhere here. I am choosing the alloy composition this and if I carefully observe, this is delta phase, this is the delta plus gamma phase, this is the gamma phase, this is the gamma plus liquid and this is the liquid phase. Am I right? And, my alloy composition is falling within the gamma.That is what it is. It is falling within the gamma because it is falling within the single phase gamma domain; at that temperature what is stable is, only gamma, in principle.

So, whatever liquid that is there, whatever delta that is there, at that temperature, at a particular point of time, they are only metastable; they are not stable. So, in principle, that liquid wants to get transformed to gamma. Similarly, delta also wants to get transformed to gamma. And, how does this happen? This happens by the process of this liquid, it wants to transform to gamma and gamma cannot take more percentage of B. Gamma can take only this much of B. According to the equilibrium,the composition of gamma in equilibrium with liquid is only this much and liquid has this much of B.

So, what happens is, the liquid gives you gamma and the excess B atoms are given out; that means, what happens is, this liquid wants to transform to gamma, but in the process it has excess B atoms. It is something like, you have seen earlier, when a liquid transforms to a solid, there is an excess enthalpy that is available in the liquid, this enthalpy is given out.This is what, we called as Recalascence.Is not it. Enthalpy of fusion; exactly similar, here the numbers of B atoms in the liquid are higher than what a gamma can take.

So, these excess B atomsare rejected out of the liquid. And, where do they go?Because there is agradient inside the gamma, the B atoms will flow towards the gamma/delta interface. So, these excess B atoms that are available will flow towards this direction because there is a gradient that is available. And now, what happen is, once these B atoms reach this, before that what has happen? A small volume fraction, some small volume of liquid, small delta x of liquid has got converted into gamma of the same composition that of gamma.

And, whateverexcess B atoms that the liquid has, it has rejected them out. And, those B atoms have started moving towards the beta, towards the gamma/delta interface and this small regionhas got converted to gamma.And, what has happened in that process? The gamma has got extended into the liquid. Some liquid has got converted into the gamma. And now, what happens is, once these B atoms reach this interface, if you look at the delta,delta composition is this. Delta has a smaller B contentthan the gamma. Is not it.And, this is the composition of delta in equilibrium with….If this delta has to get converted to gamma, it needs more B atoms because this is the difference in the B atoms between delta and gamma.

So, if the delta takes B atoms, delta has certain structure. In our particular phase diagram, delta has BCC structure. This BCC structure, takes away Carbon atoms.In our case,B atoms means Carbon atoms because we are talking about Iron-Carbon phase diagram. So, this delta takes Carbon atoms and the Carbon content in the delta rises to that of the gamma at that particular temperature,according to the equilibrium.The moment, the Carbon content of the delta reaches that of the gamma; suddenly that particular delta gets converted into gamma.It is only a structural transformation now. Composition of the delta becomes equal to the composition of the gamma. And, once the composition reaches same, suddenly there will be a BCC to FCC transformation. And, that means, a small amount of delta got converted into a gamma. And, as a result, you will see a small volume here, gets converted.

And, what is the process?The delta takes B atoms and gets converted to gamma.For the delta to get converted to gamma, it needs excess B atoms because it has low B atoms, low Carbon content. So, on that delta, once your Carbon atoms are provided to it,itcan get converted to a gamma. And in the process, if I add these two reactions, what we see is, basically is that liquid plus delta gives you gamma; because the B atoms, which are here on this side and B atom that are here on this side will get cancelled. So, you seethat basically, the same Eutectic reaction is taking place in two steps.And, this is what we call it as Peritectic transformation. We do not call it any more, as the reaction because there is no reaction here.

So, the Peritectic reaction that we traditionallycall is only at the beginning of the reaction. At the beginning, you have a reaction because there is a real interface between the liquid and solid phase.And, there is the reaction that takes place. And, once the reaction takes place, there is a third phase, which is the product phase of the Peritectic reaction comes and covers the solid that is already available.

And, once this covering take place, then the further reaction can only occur by diffusion. And, diffusion where? Diffusion, inside the product phase that has formed the diffusion is taking place, inside the product phase and which is a solid phase. Is not it. And, we all know, diffusion through solids is more difficult. Diffusion inside the liquid, Peritectic reaction is very easy. Why?Because all the diffusion of atoms that is happening, if you remember this, the alpha plus beta we said liquid, all the atom with movement is taking placeinside the liquid. And then, the both are moving faster.

That iswhy Eutectic reaction is definitely much faster than a Peritectic reaction. A Peritectic reaction needs a diffusion of atoms through the solid layer. And, once you understand this,you would see that it is very easy to understandthe Peritectic transformation. And,that is the reason why, sometimes you actually see, if I cool a system very fast,you may not see a Peritectic reaction taking place.For example, there are, what are called metastable.Is this very clear to you now.How does this happen? So, you can see, at the liquid/gamma interface, liquid, a small fraction of liquid transforms to the delta, to the gamma by releasing B atoms; because gamma cannot take as many B atoms that are available in the liquid. So, the excess B atoms are rejected out and small volume of liquid gets converted to gamma.

And, in the process, now the B atoms that are rejected out, travel through the gamma and then reach the gamma/delta interface and get added to the delta which is available and the Carbon content of the delta rises or the B content of delta rises, in such a way that some part of the delta gets transformed to that. And, all this is driven because of the diffusion. And, again we all know, J is minus Ddc by d x. Now, what is the dc by dx here, what is the d x? dx is nothing but the thickness of the gamma. Am I right? dx is thickness of gamma and what is the dc? dc is this, composition difference; The composition differencebetween the C gammaliquid and C gammadelta.

So, delta Cfor our case,here is delta C.Delta Cis Cgamma liquid minus Cgamma delta. That is what actually drives. And, again if you look at this difference, this difference at the Peritectic temperature is, what?It is 0.At the Peritectic temperature, this difference is 0 because both of them are meeting here.At the Peritectic temperature, all the three are in equilibrium. So, there is a single common tangent for all the three phases. So, the composition of gamma in equilibrium with delta and the composition of gamma in equilibrium with liquid is always the same. And, if that is the case, same then this is 0. If this is 0, the gradient is 0.If the gradient is 0, then the flux is 0. So, there is absolutely no possibility of any Peritectic reaction to occurat the Peritectic temperature. You need to come below the Peritectic temperature.

And again, the way we have talked in the case of Eutectic,the lower the temperature that you come, below the Peritectic the more this widens. So, the higher under cooling that I provide is useful.Keeping again at the back of our mind, if your diffuse ability always plays a role because this fellow is sitting here. So, as long as I remember that, so I know that the higher under cooling increases this. And, when it increases, you will see definitely this increases. If this increases, flux will increase.But,there is one more issue here. The second issue is, as the transformation progresses as a function of time, what is happening?Now, as a function of time, if you carefully look at it, the gamma isbecoming thicker.

The gamma is growing both in this direction and in this direction because a small amount of liquidhas got converted to gamma and the small amount of deltagot converted to gamma. So, what is now the gamma thickness? Gamma thickness is thicker than what it was before. So, if the gamma thickness is increasing, in our… this equation,the denominator is increasing; dx is increasing. If the dx is increasing, obviously the gradient decreases.And, in the gradient, if the transformation is taking place at a fixed temperature, dc is always constant. The delta C, which we have written here, is only dependent on the temperature.Because at a given temperature, the phase diagram tells you, what is this composition and what is this composition.Once, I fix up my temperature of transformation; that means I have under cooled the liquid to certain extent and there the reaction is taking place.

Then, if that is taking place at that temperature, you would see that in principle, at that temperature these two compositions are fixed.And, that means the numerator is fixed. But,the denominators is now increasing as a function of time; that means, Peritectic reaction slows down as a function of time. So, you see that, initially it starts at a faster rate, but as a function of time, you will slowly see it decreases. That is the reason why, at very higher under cooling if you give, there may not be any Peritectic reaction, significantly occurring; because at that temperature D itself is slow. D is slow and this is larger. So, both of them will lead you.And, this is something which we need to understand. Now, this leads us to what are called metastable phase diagram.

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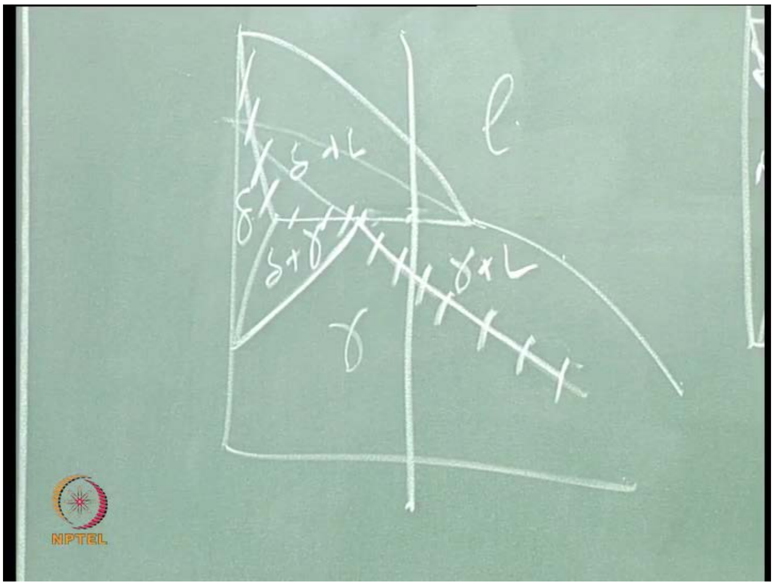

What is this Metastabilitythat you get in?Becausethis reactions are slower,for example, liquid to reactive with delta to give you gamma is not easy because liquid has a different composition, delta has a different composition. And, as the result, ingamma hasfilled different composition. And,the structures are different and also, this reaction needs essentially a diffusion through the solid phase. And, because of which, there can be situationswhere the reaction may not occur at all. And, that can be easily understood, if we look at this phase diagram, a little more closely.

If I simply look at this phase diagram and extrapolate these two curves,what are these two curves?What is this curve?Can you tell me? It isSolidus.And, what is this curve then?Solidus? both are solidus?

What is the solidus?...Tell it in the form of a sentence, put your words together and then frame a sentence and tell me what is solidus?Anybody else who are?And, if I ask you to think of, some other definitions for it?Composition,you are saying equilibrium with liquid has.And, what is liquidus? is also sustain yes again

What is the definition of solidus?The temperature at which the solidification is complete;the temperature below which there is no liquid that exists is a Solidus;where the solidification is complete. And, what about liquidus then?Where the solidification starts.The temperature below it; you start seeing the solid, first from a liquid. If that is the case now, what are these phase boundaries? Again look at it.This is liquid, what is this?This is delta and this is gamma.What is this?It is a solvers line.It is not solidus line. Please understand.

And, what is solidus here?Can somebody draw it?Let me see.Yes.You seeyes andthen,why do not, you put down the phases?Then it becomes easier for you.What isthere on the right side of gamma?

So, what about this portion of the Peritectic? That cannot be called as solidus. You are right.This is what, differentiates between a Eutectic and a Peritectic.Let us draw again a Eutectic for the sake of argument.Now, on this Bala can you come and draw what is the solidus here?Alpha.That is it.In a Eutectic phase diagram, the whole Eutectic horizontal becomes a part of thesolidus.Whereasin the Peritectic,only a part of the Peritectic falls into the solidus and the remaining part does not. Because below this line you still have the liquid left out. If some liquid is left out, then obviously it is not solidus.Right. And liquidus line is easier; the top portion. Similarly, here also the liquidus is easier. The only confusion that comes always is a solidus.Now let us come back to other question, which we wanted to start again. I may have to reverse this a little. Let us, do that.

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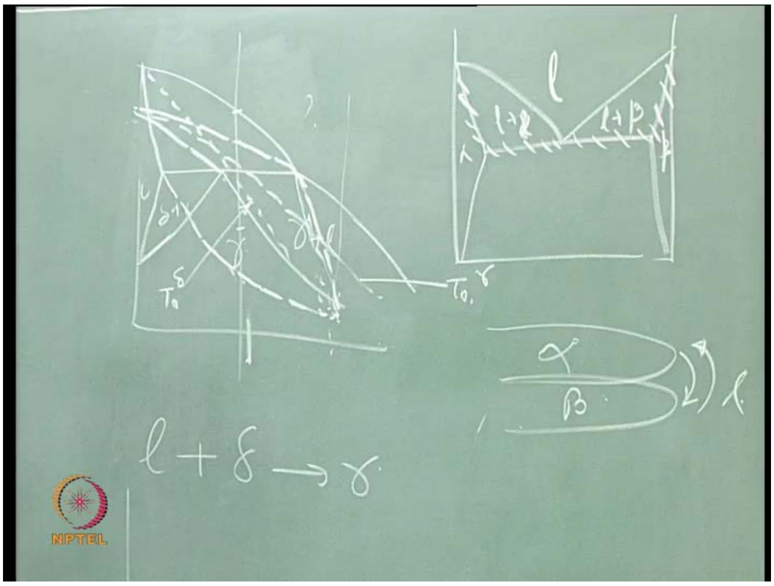

If I extrapolate these two curves, which is this is the..,what is called the gamma? This is gamma plus liquid. So, this is the liquidus. You call it as, whatliquidus is this?It is called gamma liquidus. This liquidus is called the delta liquidus. By now, you should… because we are talking more and more about equilibrium of liquid with one phase. So, you should slowly start understand because possibly, earlier when you are talking about phase diagrams, we never talked about gamma liquidus and delta liquidus.

Similarly, when we talk about this liquidus; this is alpha liquidus, this is the beta liquidus. Though both are liquidus, but the liquid on this side is in equilibrium with alpha; liquid on that side is in equilibrium with beta. So, these things have to be engrained into you, as you go along. So, what we see is that, whenever this reaction is very difficult, the system chooses any one of the two cases. Either, it will become like this or if I draw; may be here itselfyouwill do.

We will reach a situation something like this.Within… which phase this is more difficult to nucleate. From the liquid, depending on the structure of that particular phase, whether gamma or delta is more difficult for to nucleate, the system will choose that particular phase which is easy to nucleate. And, whenyou cool the liquid rapidly, only that phase comes out. Rather than one phase coming out first and that is reacting with the remaining liquid, giving you the second phase. You will see that the whole phase diagram gets converted into an isomorphous, for type of phase diagram.

You see that,for example,here if I unfortunately…,I do not have color chalks,if I have itwould havebeen easy, you will see that this gets converted into a kind of isomorphous. You say that this is a liquid delta isomorphous. So, the liquidus of the delta liquidus, I will extrapolate. The solidus of a delta, I extrapolate and when both of them meet at some place that gets converted into a liquid delta. And, now if you cool this liquid rapidly, you will see simply, only delta coming out. And, if I can calculate what is called T naught curve for the liquid delta T naught curve.And, if I do my under cooling such that, I am below the t naught, I will get partition like solidification; where liquid transforms to only delta. And, in principle, after the reaction is over, I will see only delta, there is no gamma at all.Provided, my cooling rate is fast enough that there is no time for such a reaction to occur.

And, in principle, if the gamma formation is easier than a delta formation;if the structure of that is such that; I am simply giving some example. I do not know, what is gamma, what is delta.Let us not simply relate it to Iron-Carbon phase diagram. There can be any phases. If that is the case, then what you willsee is that, there will be an extrapolation of this into that.Such that, when I am cooling this liquid, what I simply get is the gamma directly.That means I need to under cool the liquid, below this equilibrium liquidus, lower equilibrium,a lower liquidus, which is the metastable liquidus between the liquid gamma phase equilibrium; that means,this is the gamma liquidus if I extrapolate, wherever this gamma liquidus goes.

And, if I can bring the liquid below the gamma liquidus, it may under cooling such that, I come to below the gamma liquidus, then in principle, gamma can nucleate out of the liquid. And, if I under cool to certain extent that I am below the T naught curve, this is now, what is the t naught?This is the T naught, this is the T naught for gamma for me.The earlier T naught that I have drawn here, is the T naught for the delta.

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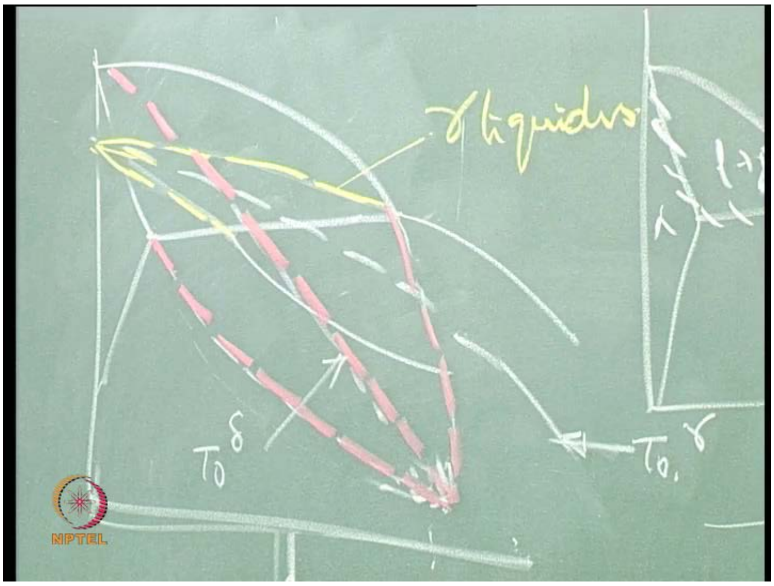

If you want, I will draw it little more carefully. Too many curves possibly, confusing you.That iswhy; I should have some color chalks.This is what is the T naught gamma. This is that T naught gamma.And, if you extrapolate this,what you get is T naught delta. So, depending on where you are,you can get basicallyany of those phases. And, if I can under cool below the T naught of gamma, then in principle, yes, I can get partition less solidification of liquid giving you single phase gamma.

So, you can see clearly. Now this is extrapolation of,this is what the gamma liquidus is for me.And, as a result, this would be for me and for being very careful these two lines have to meet at a point. Ultimately, what is the left axis?It is a pure metal for me.That is why, if you rememberin the question paper that you had; possibly, in the next class we will take up that question paper and try to solve that. So, you should see that these two ultimately should reach the same point. And, this is the T naught that we are talking about.

And now, if I look at the other phase, this is the… you can see…that is the T naught of delta. So, depending onmy under cooling and also depending on which phase is easy to nucleate,I may geta partitioning solidification;solidification withpartitioning giving you either delta or gamma or solidification without partitioning giving you either delta or gamma. So, you can see that a normal phase diagram now,some of them gets suppressed.

For example, one simple easy similar thing, I can even see this.There is a very famous phase diagram called Magnesium-Silicon phase diagram. Anybody knows about it?This is an important phase in Magnesium-Silicon phasediagram, which is very importantfor, you know Aluminum alloys particularly.

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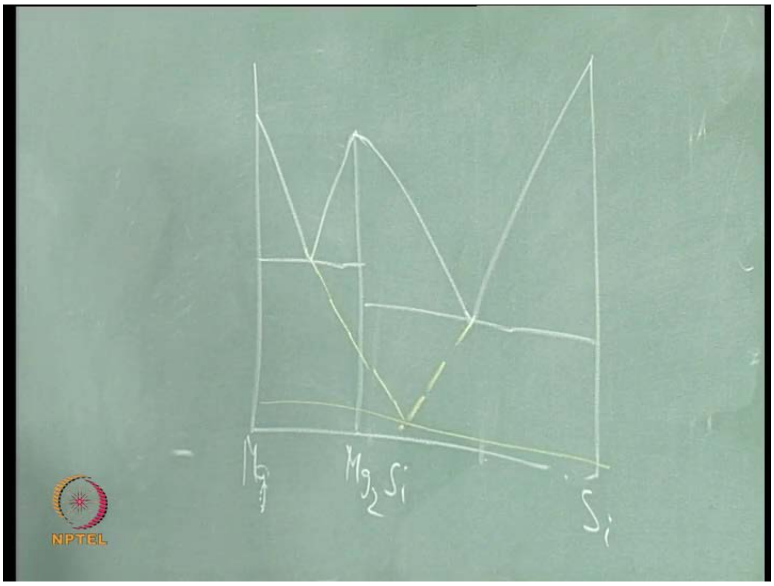

What isthat? Mg_2Si. Good. So, Mg_2Si,if you carefully look at it,there is Mg_2Si here. I am sorry.M it should be here because it is…Mg_2Si. So, Si is one. So, we are on this side onlyand then this is Silicon. And, you have a Eutectic between thesetwo; this is the typical Magnesium-Silicon phase diagram with Mg2Si. And, now if I take this alloy Mg_2Sicomposition and if theMg_2Si crystal structure is such a complicated crystal structure that I am cooling this liquid very rapidly.And so, the nucleation of this Mg_2Si is very difficult.Then, what should happen to that liquid?That liquid will not give you Mg_2Si.

And, as a result, what happens actually is that, this liquid gets under cooled to certain extent that if I extrapolate this liquidus curve,I get another liquid there; another Eutectic there. And, thisEutectic that you generate is a metastable Eutectic.If this phase does not form, if it cannot form because of any reason, then you see that the liquid gets under cooled and becomes stable.And, to such an extent this liquid can be easily become a glass. Because that liquidus now,is closer to the Tg let us say. Then, it can easily become a glass. So, there are many phase diagramswhere,particularly when there are inter metallic compounds, they do not form and suddenly that liquid becomes a glass. So, this is what is metastable phase diagrams, which is very important.Thank You.