Phase Equilibria in Materials (Nature and Properties of Materials - II)
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Lecture - 16
Intermetallics & Phase Diagrams

So, welcome again, we start with Lecture 16 now.

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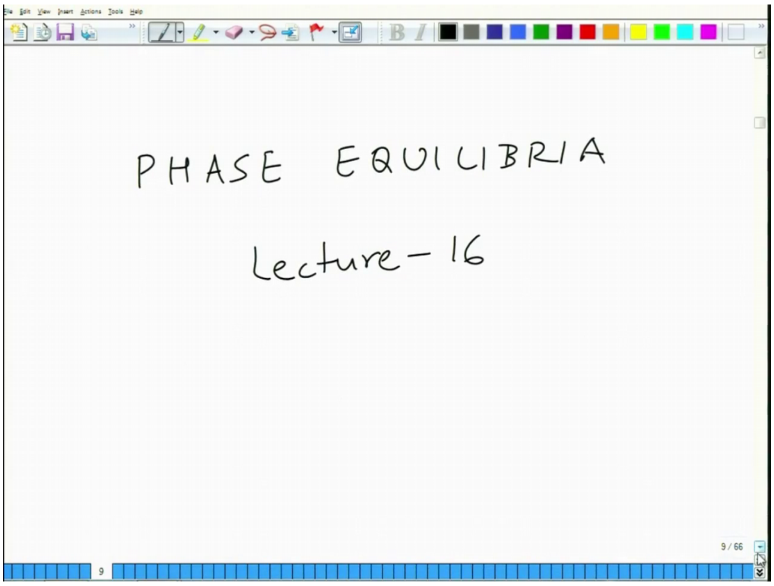

So, in the past lecture, in the previous one we looked at the basically in the previous lecture we looked at. So, just recap.

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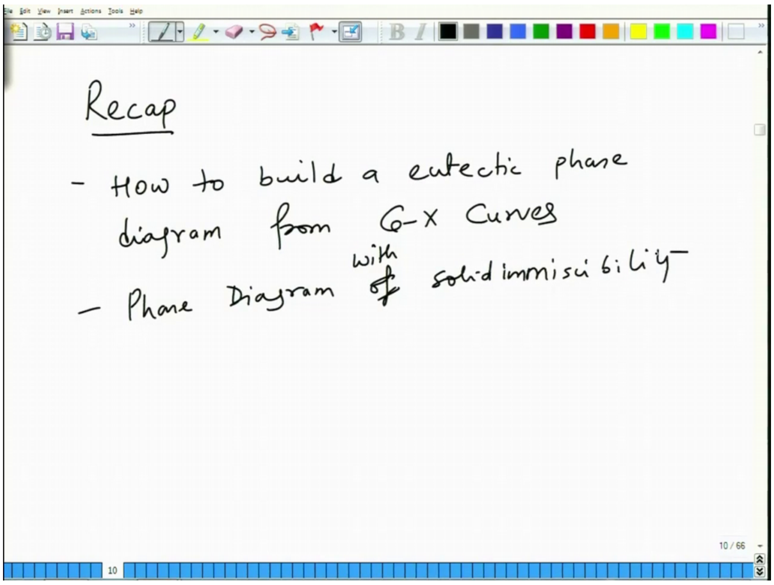

We looked at how to build a eutectic phase diagram and then we looked at phase diagram of solid phase diagram with solid immiscibility. So, if you go back to this slide, so, what we had was we looked at various temperatures.

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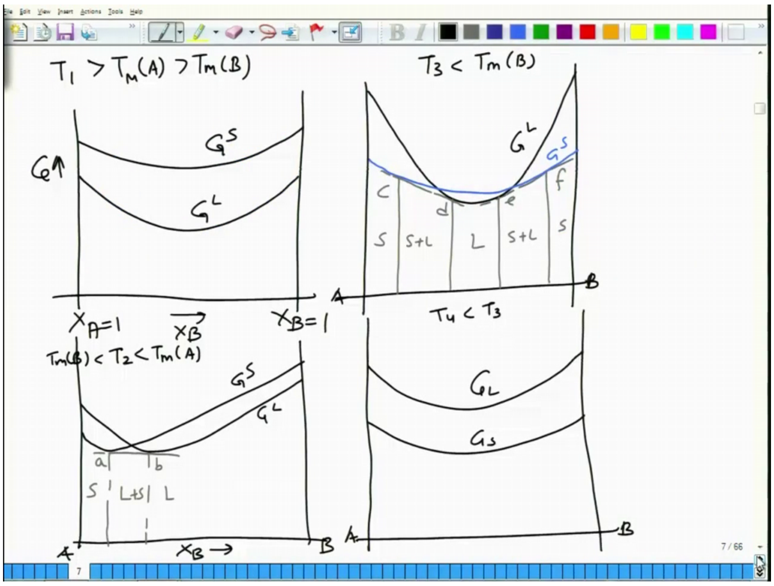

So, higher temperature solid and liquid are that is all liquid is more stable than solid and A and B are miscible into the each other, at lower slightly lower temperature the first solid forms and solid and liquid region is there and liquid is.

So, you have solid below a, liquid plus solid between a and b and above b you have liquid. Now, when you lower the temperature further T 3 lower than the melting point of b what you obtain is a slightly interesting thing instead of having purely solid you would have expected in a material with solid solubility complete solid solubility that, this liquid has would have gone up and you would have only solid phase, but what you have is you have, rather flattening of this solid curve with respect to liquid curve. In such a fashion so, that solidus solid liquid phase curve is lower than the liquid phase curve on the two sides of the phase, fringe landscape.

But in the intermediate composition range it is higher. So, as a result you are now you can now draw two tangents one on the a rid side, one the b rid side and on the intermediate composition liquid is more stable. So, you can see that now you have two, solid plus liquid regions in between you have a liquid region. So, which means liquid is in this composition range liquid is more stable to even lower temperatures and then, when you come to temperature T 4 which is lower than T 3 the solid is of course, more stable than liquid.

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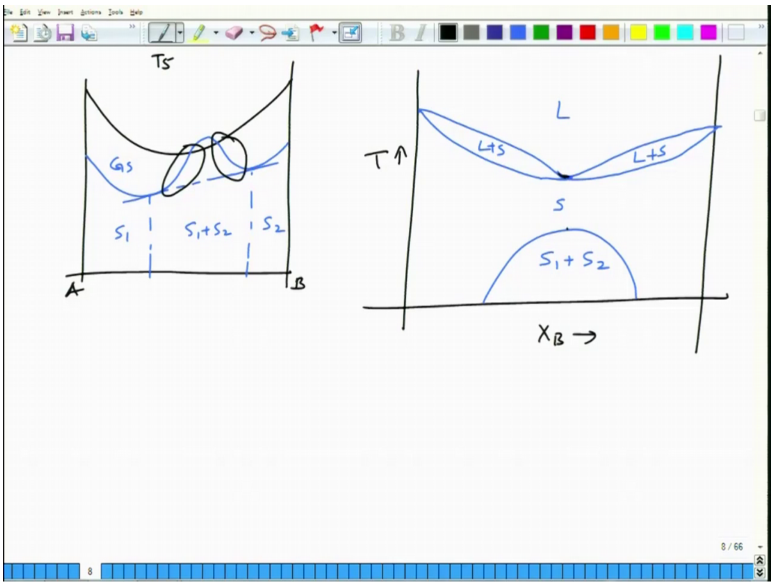

And at even lower temperature T 5 the solid frigid curve changes a bit the solid frigid curve has a formation of a curvature.

So, you have a curvature here. So, this formation of this change in the frigid plot for the solid phase is signature of solid phase converting into two phases, because it has now two minimize. So, one minimum phase 1 second minimum phase 2 and a common tangent again will determine the composition boundaries of phase 1 and phase 2 and 2 phase region.

So, what you when you construct the phase diagram? So, I am not drawn many of those curves inter intermediate, but when you draw a phase diagram for such a system you have this kind of system. So, you have liquid, stable at high temperatures, which have a formation of solid lower temperatures, but this liquid s has a minimum it has a minimum at this up to this point and before the whole of the liquid converts into solid. So, at this point liquid directly converts into solid, at a minimum at a melting point which is lower than a melting point of either a and b.

So, you are stable the solid the solid the completely solid phase single phase solid region is stable up to certain temperature. And once you reach this temperature the solid further decomposes into 2 more solids s 1 and s 2 is called as phase separation and you form, system where solid solubility especially in the solid phase of a and b is not great.

So, this is another system that you can obtain in terms of Phase diagrams, you can have systems with Delta H, mix in solid-phase, less than 0.

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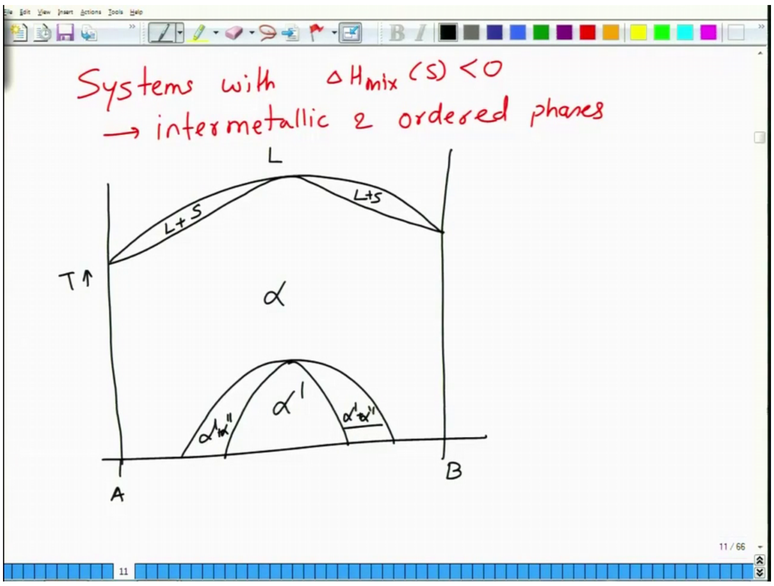

So, one was eutectic system, but you can also form intermetallics and ordered phases. So, now, it is difficult to go through it is we do not have time to go through free energy composition of each of them, but I will just draw the free energy, I will just draw the phase diagrams what I would request you is that you go through phase diagrams and try to draw the corresponding free energy composition curves at various temperatures and then plot from those free energy composition, curves get back the phase diagram again.

So, for instance you have a situation like this in which, you have. So, you have liquid plus solid. So, this is temperature and then you have solid phase, the solid phase again converts into another solid phase alpha prime and you have a two phase region alpha prime plus alpha double prime. So, this alpha prime is the special compound it could be inter metallic or, some other ordered phase, you can have a phase diagram which is little more complex like this.

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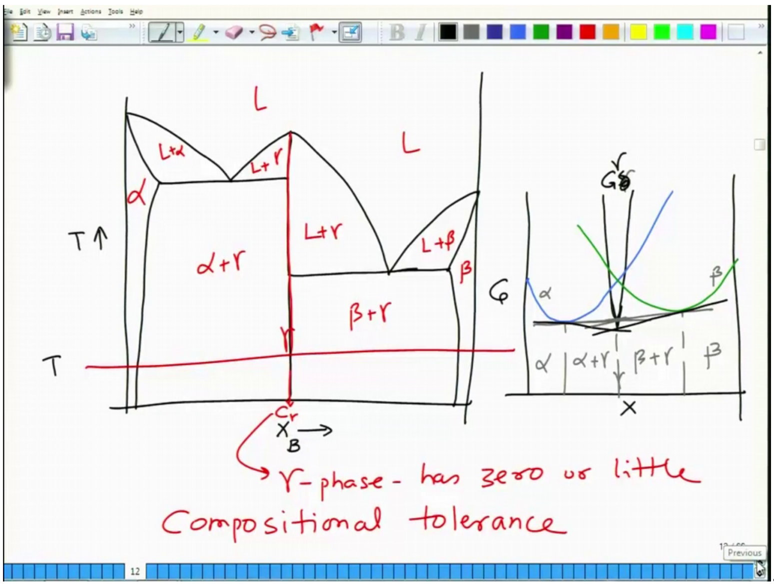

So, you have looked at the so, this is even more complex phase diagram. So, here you can have you know this is all liquid.

So, here there is a single phase region alpha this is single phase region beta in between you have a line compound gamma. So, this is the line compound gamma. So, this is C gamma and on the right side you have liquid plus gamma on the left side you have liquid plus beta here you have again liquid plus gamma liquid plus alpha in between you have alpha plus gamma and here you have beta plus gamma.

So, this is again a possibility where, this gamma phase has 0 or little, Compositional tolerance. So, for instance when you draw the free energy composition at this temperature let us say. So,. So, this is let say T 1, I plot g versus x. So, you have now this gamma phase has little composition variation as a result it is free energy curve is going to be something like this is g comma and then you have alpha and beta.

So, the alpha phase would be somewhere like, you have alpha phase free energy curve like this of course, it would be slightly higher and then beta phase would be something like that and when you draw the common tangent between these not at really right level and for this again you will have another tangent; these both tangent will form to the same point. So, you will have. So, this is alpha this is beta this is G gamma. So, this is alpha, this is alpha plus gamma and this is gamma, this is beta plus gamma and then beta. So, this is how the free energy curve will probably look like this gamma will be a little more deeper as compared to you can say it is more like that ok.

So, this is how the free energy composition will look like the gamma phase it will have very, very narrow free energy curve as compared to alpha and beta phases. So, this is another kind of Phase diagram that you can obtain, you can have a Phase diagram something like you can have a Phase diagram with the intermediate phase.

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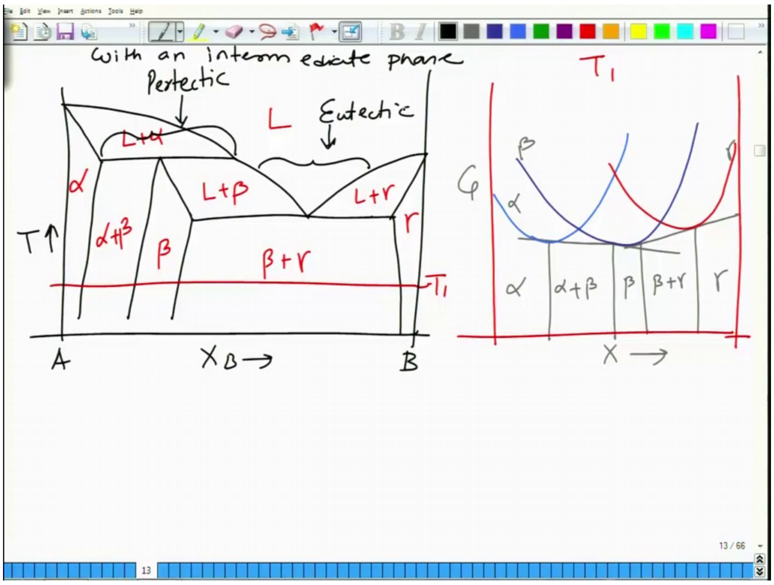

For example, so, with an intermediate phase which has certain composition tolerance, so, you have a Phase diagram like this you have liquid. So, let me just first construct the Phase diagram and there will be something else at lower temperatures.

So, I am not going to draw the lower temperature one. So, you will have X B. So, you can see that, this is liquid or liquid this is single phase alpha, this is single phase gamma in between you have beta. So, this is alpha plus beta, this is liquid plus alpha this is liquid plus beta this is liquid plus gamma then you have beta plus gamma. So, you have at this you have this intermediate phase beta, which is not exactly line compound, but it is compositional range is narrow as compared to, fairly narrow. So, this is my intermediate phase and this is a fairly complex phase diagram.

So, if you wanted to draw a composition free energy composition plot at this. So, let us say this is T 1, what you would have is you would have, now this beta will have fairly, white curve. So, this would be beta, this would be alpha would be gamma. So, you can draw the common tangents now this is the common tangent for this is the common tangent for this. So, we will have alpha, alpha plus beta, beta, beta plus gamma, gamma this is alpha this is beta and this is gamma. So, this is what G versus X would look like. So, these are certain phase diagrams with various configurations. You can have another phase diagram if you have.

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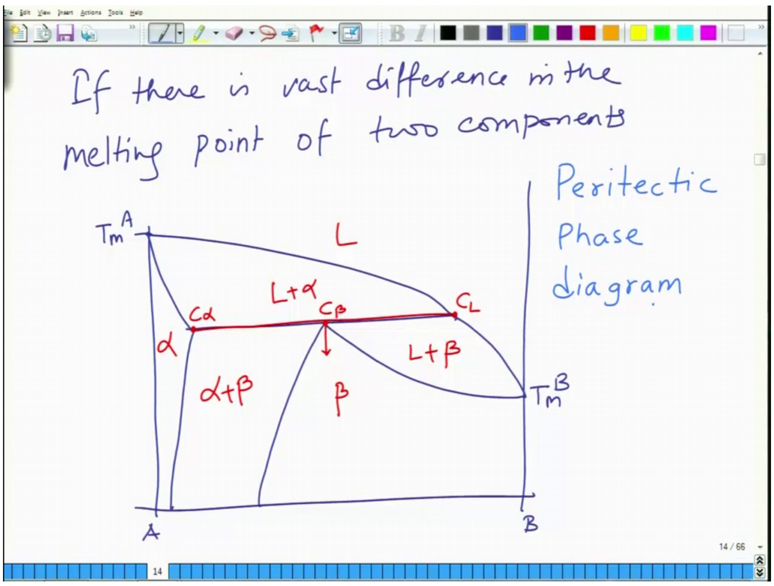

If, there is vast difference, in the, melting point of, two components. So, what you can have is something like this? Ok. So, let us say this is a this is b. So, this is T M A this is T M B. So, you have liquid you have alpha you have beta. So, liquid plus alpha, alpha plus beta and this is liquid plus beta. So, what happens is that, you have now you can see where do the three phases coexist this is the line along which three phases coexist and this is a temperature this is the composition and temperature at which liquid of this composition and solid of this composition react together to form beta of this composition

So, this is say let us say, liquid C liquid this is C alpha and this is C beta this kind of Phase diagram is called as Peritectic phase diagram; peri, tactic, phase diagram. And basically what happens here is in terms of phase reaction.

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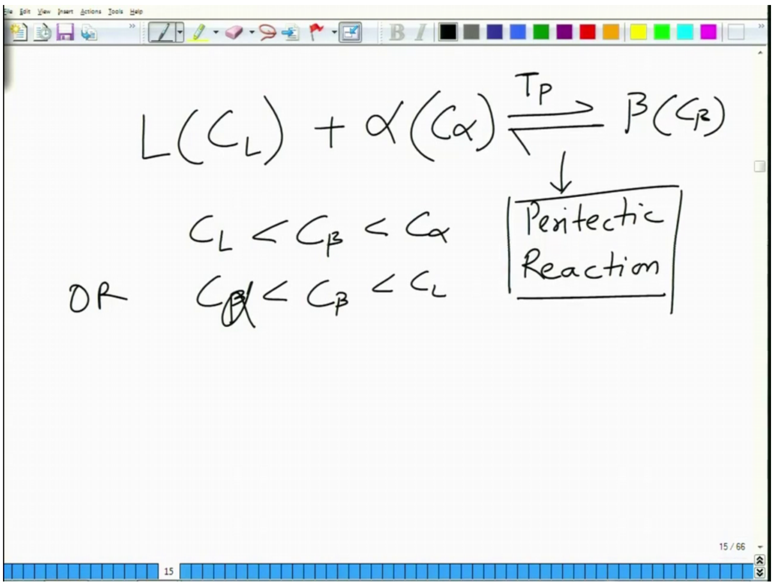

The liquid of composition C liquid, plus, solid of composition C alpha, give rise to at a Temperature T P Peritectic temperature, beta phase of composition C beta where C beta is between, C alpha and C liquid or you can say it is C beta between C liquid, depending upon how you look at it how you look at it is between the alpha and liquid compositions. So,, this is the Peritectic Reaction it happens when systems, in case of systems where two elements have vast difference in the melting points.

Typically Peritectic Reaction occurs in conjunction with other Reactions. So, for example, if you look at the previous slide, this is what is the Peritectic region. So, this region is the. So, this is this is the, Peritectic part and if you look at this region this is the

Eutectic part. So, all of these directions they tend to coexist with each other, making complex phase diagrams. So, again you can draw the free energy curve free energy composition diagram for this, which should be fairly straightforward at this point. So, I would recommend you to go through these various possibilities and draw the free energy composition phase diagrams. So, this is a Peritectic Reaction it is called as Peritectic Reaction.

So, these phase reactions we looked at Eutectic phase Reaction we looked at Peritectic phase Reaction there are a few more phase Reactions which are of interest as well as phase diagrams are concerned and two of them happen in solid state, I am not going to through I am not going through all of them, but just few common ones.

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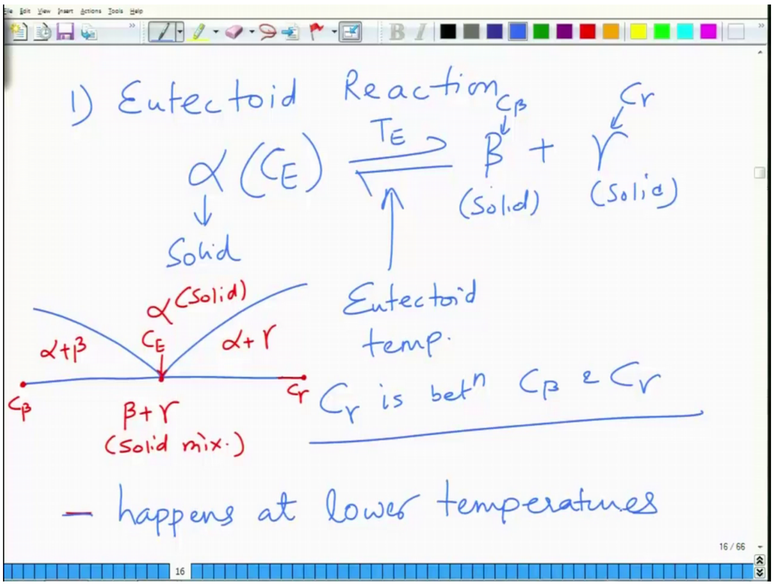

So, there are other Reactions such as Eutectoid Reaction, in the Eutectoid Reaction the alpha phase of composition C E, which is solid phase, transforms into 2 more solid phases. So, this is again solid and this is again solid at a temperature T E which is a Eutectoid temperature not Eutectic temperature eutectoid temperature and of composition C beta and of composition C gamma.

So, where C E is between, C beta and C gamma just like Eutectic Reaction where liquid of composition C E which is between C alpha and C beta, here solid of composition C E which is between, which converts into 2 solid phases beta and gamma, where C beta and C gamma are above and below the, Eutectoid composition.

So, again at this eutectoid. So, basically you can say schematically it this reaction is something like this. So, you have alpha, of composition, C E transforming into beta plus gamma where beta can have this composition and gamma will have. So, this is C beta, C gamma. So, this is again both solid, mixture and this is again solid. So, this would be alpha plus beta this would be alpha plus gamma. So, this is analogous to eutectic reaction except that it happens in the solid phase and as a result it happens at lower temperature. So, we can say it happens at lower temperatures. There is another reaction that we can talk about is the.

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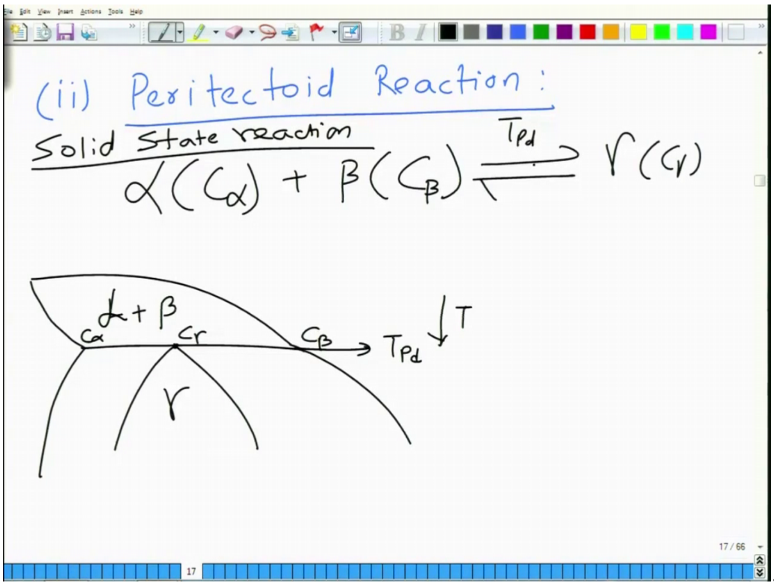

Analogous to peritectic reaction another reaction is peritectoid reaction, in the peritectoid reaction it is alpha of composition C alpha, plus beta of composition C beta, give rise to gamma phase of composition C gamma all three are in solid state. So, these are all Solid State, Reaction. So, it is something like this you have ok. So, this is alpha plus beta giving rise to gamma phase. So, this is let us say C alpha this is C beta and this is C gamma and a temperature is T P. let us say, T Pd ok. So, this is.

So, in this case you can say it is T Ed. So this is peritectoid temperature at which alpha of composition c alpha, beta of compositions, C beta together transform into gamma phase. So, this is lowering of temperature, in the previous case the temperature goes down like this. So, this is called as peritectoid reaction at temperature T Pd.

So, there is a phase diagram which consists of many of these Reactions for example, the famous diagram is called an iron carbon phase diagram that we will look at, in detail in this course later on.

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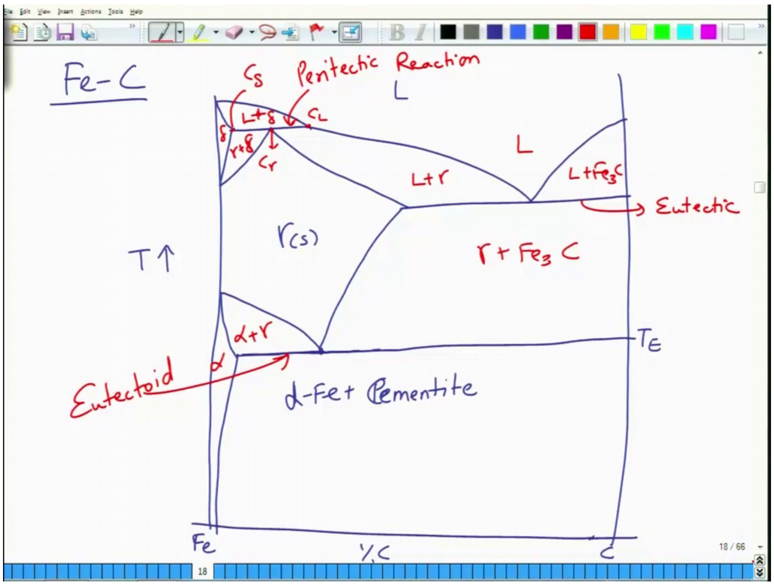

So, if I now plot this diagram this is a very interesting diagram it consists of nearly everything. So, at lower temperature. So, on this is percentage carbon pure. So and this is carbon, step picture and again at high temperature what is there is.

So, you have liquid phase here this is gamma solid phase, this gamma phase converts at this temperature which is T eutectoid temperature to two phases called as alpha iron plus cementite. So, this is eutectoid reaction here, at this temperature liquid converts into what we call as, this is liquid plus gamma, this is liquid plus Fe 3 C and what you have here is gamma plus Fe 3 C. This is eutectic eeaction and at this point liquid plus, delta converts into. So, this is this is liquid of this composition C L, C delta converting into C gamma. So, this is a peritectic reaction.

I will draw a more precise diagram that the composition have shifted a little bit here this is, 0.8 percent this is less than 0.8 percent and so on and so forth. So, I will draw a more precise diagram perhaps when we discuss and this is delta phase, this is gamma plus delta and. So, so you can see that in one phase diagram iron carbon you have Eutectoid Reaction you have Eutectic Reaction and you have peritectic reaction. So, there are possibilities in which all the reactions many of these reactions can be combined in a single phase diagram.

So, I just want to illustrate that for you, to have a, feel of how complex the phase diagrams can be. So, you can go home and. So, I would say this is sort of for homework for you.

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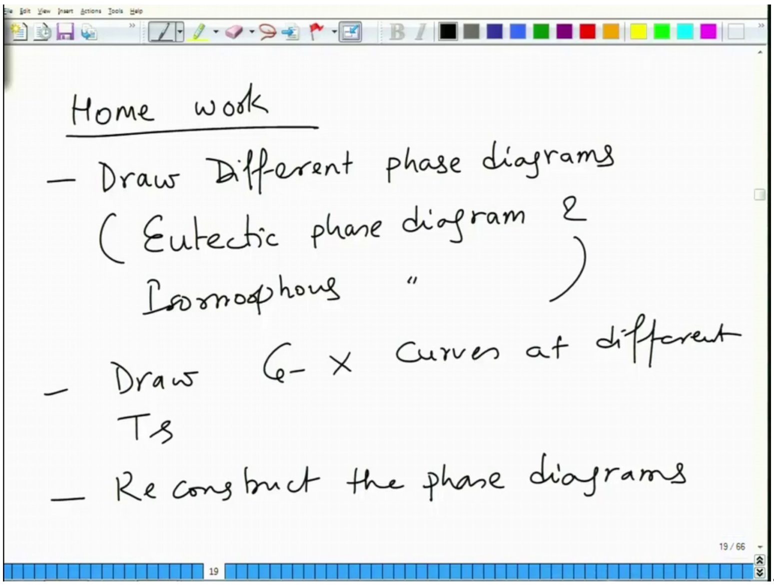

So, go over draw different phase diagrams especially the eutectic ones and let us say the isomorphous one. Draw G-X curves, at different temperature, Ts and then reconstruct the, the phase diagram. So, this is very important exercise for you do for you to do to understand how the phase diagrams evolve from first principles.

So, now we are coming at a at a juncture where we are going to shift our gears into understanding phase diagrams in a in terms of phase formation and, micro structural development. So, what we have done until now is to establish a thermodynamic framework consisting of topics on free energy enthalpy entropy. So, that we are able to draw a free energy curve of different phases and since any system has at least you know if you look at the simplest of the systems you will have at least liquid solid phases if we do not go to you know hype, very high temperature where we have vapour phase. So, it will at least have liquid and solid phases which will give you various combination of phases depending upon the composition that the miscibility of solids into each other that difference in crystal structure.

So, we looked at real solutions we looked at regular solutions ideal solutions sorry we look the order was we looked at ideal solution the regular solution then real solution and the differences are basically caused by atomic interactions. How atoms are receptive to each other, which is determined by the size differences bonding electron negativity and so on and so forth.

What we have done is we have developed the thermodynamic basis to evolve the phase diagram. So, practice over these extensively I have told you the books porter and easterling phase chapter face transformation materials or even physical myth, physical metallurgy of materials physical metallurgy by Raghavan. These are two books even Gaskell thermodynamics of Metallurgical thermodynamics can be useful book go through these rigorously to understand the phase diagram evolution completely. In the next class we will discuss some more aspects of phase diagrams before we, get into micro structural development.

Thank you.