**Phase Diagrams in Material Science Engineering**
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**Lecture – 50**
**3 Phase Equilibria in Ternary Systems-I**

Students, we have started discussing on 3 phase equilibria in ternary system, and, I just told you that, the 3 phase equilibria, consisting of Alpha Beta and liquid, can be represented by its ternary tie triangle. I hope you remember that I discussed with you about, ternary tie triangles, and this basically, is tie triangle connecting 3 phases, and, we have, I have given you a brief outline of what is that. So, before that let me just tell you, that, you know how the ternary tie triangle looks like.

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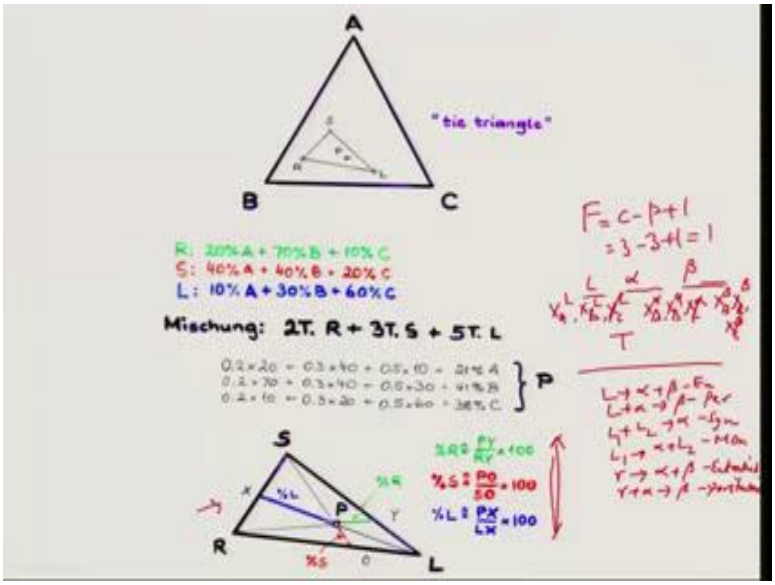


Well, this is Gibbs triangle, A B C. Suppose we have a phase. We have a, sorry, alloy composition given by point P here and, after some transformation from liquid to solid or solid to solid, it forms 3 phases, given by S R L. So, the points on the Gibbs triangle connecting the compositions of these 3 phases is S R L basically represented by a Gibbs tie triangle, and this can be used to measure volume fractional phases (Refer time 01:35) I am not going to go the details of that. The bottom construction here is showing the same thing that, how, the phases can be determined easily, as you see that the different

lines can be done and one can determine the percentage of phases. This has been integrated in the slide, and I have discussed to you in the class also.

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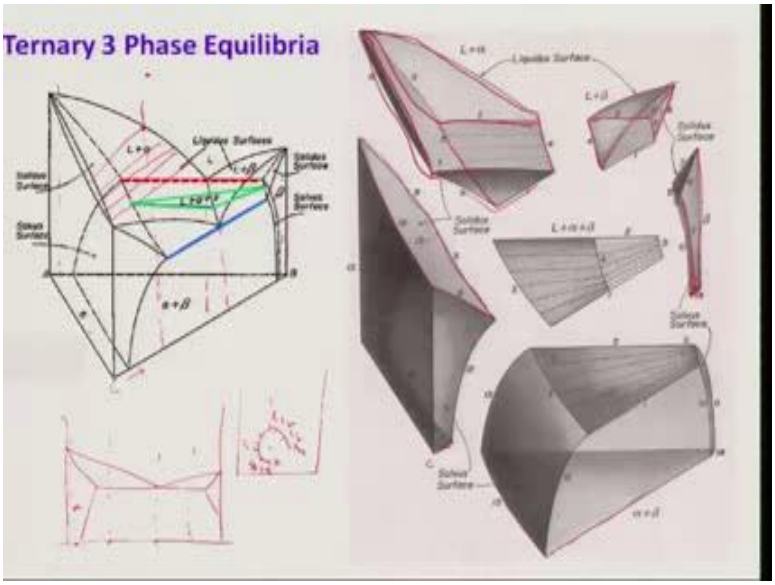


So, well, there are, well, as you know there are, in a ternary system, let me just go back, in a ternary system there are actually 3 components. So, degrees of freedom, F is given by C minus P plus 1. So, there are 3 components, and we are discussing about 3 phases. So, degree of freedom is 1. So, in the 3 phases there are 9, there are 6 independent composition variables, right? Why? You have suppose liquid, Alpha Beta has a 3 phases. The compositions of liquid are represented by 3 elements xaL, xbL, xcL; right. Similarly for Alpha also xa Alpha, xb Alpha, xc Alpha and Beta also, xa Beta, xb Beta, xc Beta, and you know that xa plus xb plus xc equal to 1 for a particular phase, liquid Alpha or Beta. So, therefore, we have 6 independent composition variables.

The last one is sort of (Refer time 03:13) determined by the relationship I told you, xa plus xb plus xc is equal to 1, correct? So, for liquid is xaL plus xbL plus xcL is equal to 1. So, if I know one or two of the variables known then third one is automatically determined. In addition with that we have temperature and variables; there are seven independent variables, right? So, out of these 7 independent variables, one of the degrees of freedom is 1 correct? So, that means, that we can vary one of the variables, others cannot be varied at all, all the other variables, according to Gibbs phase rule.

Now there are different types of, you know, 3 phase equilibria exist. What are these 3 phase equilibria exits? One is; obviously, liquid going to eutectic, Alpha plus Beta, second one is, this is the eutectic, second one is a peritectic, liquid plus Alpha going to Beta, is called peritectic. Third one is liquid L1 plus L2 going to Alpha that is syntactic, and, another one, liquid going to Alpha plus L2, this is monotectic, and finally, you have two solid state reaction, eutectoid eutectoid and peritectoid, peritectoid.

So, many 3 phase equilibria possible, 6 actually, but, you know, it is not possible for us, for me, to discuss each of this 3 phase equilibria. Each of the 3 phase equilibrium, in terms of the ternary phase diagrams. So, we are going to, I am going to show you some of this 3 phase equilibria, in a ternary space model, but I am going to concentrate on the particular 3 phase equilibria, which is more common, and discuss further about that. So, what are these diagrams? Let me tell you. Suppose, you have the first one, which is shown here, slide.

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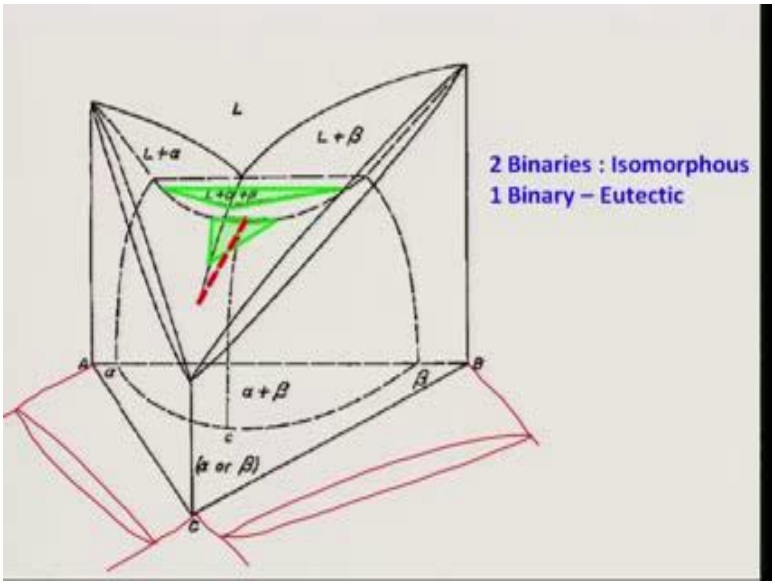


You can have, out of the 3 binaries, ok, there are 3 binaries. Suppose this is one binary, A C, ok? This binary has isomorphous themselves, correct? Then you have another binary, b c, that is also isomorphous, phase diagram between themselves, and third binary, which I am not drawing, has a eutectic reaction, liquid going to Alpha plus Beta. This is, this will lead to you 3 phase equilibria between liquid plus Alpha plus Beta, correct? And as I told you, the 3 phase equilibrium can be represented by a tie triangle

that is what is shown here, liquid plus Alpha plus Beta. We will discuss more about that in later.

So, this is the first type of, you know, 3 phase equilibrium system we can discuss. You have, please remember that, the first ternary phase diagram I discussed with you in detail is basically, isomorphous system, in which all the binaries, between a and b, b and c and c and a, form, basically are basically isomorphous type of phase diagrams. So, ternary phase diagram is also isomorphous. Here, because one of the binaries shows a eutectic phase diagram, the equilibrium condition gets, the equilibrium situation gets changed, and it becomes 3 phase equilibrium. No longer way we have two phase equilibrium existing in the ternary system. We can also have the situation, in which, one of the binaries, like here Ab.

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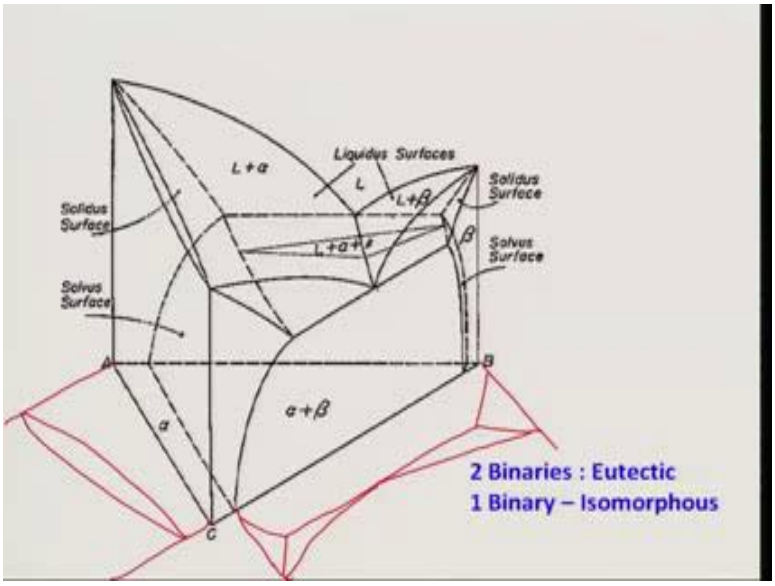


You can see is, basically, isomorphous type, but I have two binaries, are eutectic type, you can clearly see here, eutectic, third one I am not drawing. And then we also have 3 phase equilibrium at the centre.

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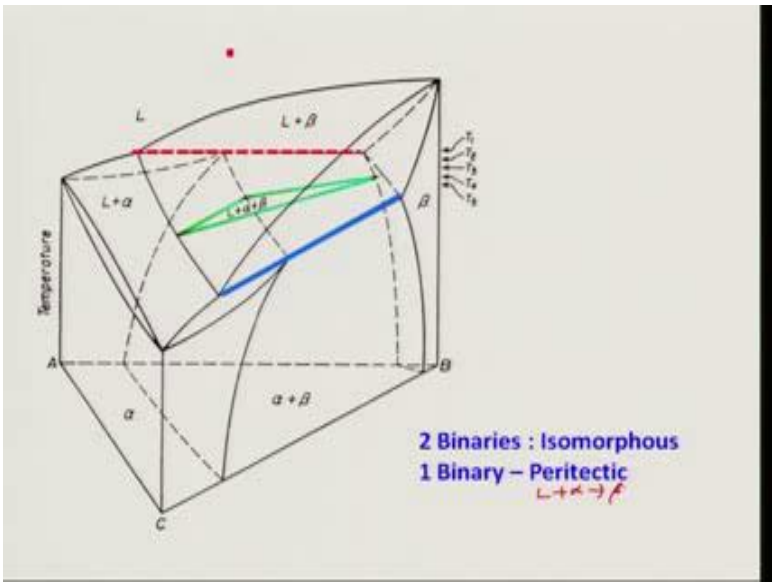


The third one, so, first one was two binaries were isomorphous one eutectic second one was two binaries were isomorphous eutectic, one was isomorphous, Third one is that, two binaries will have isomorphous systems, but, one binary will have peritectic. You can clearly see two binaries, a c and b c has a isomorphous, but on the other hand, binary between a and b has a peritectary action. What is that peritectary action? Liquid plus Alpha going to Beta, correct, this is the third situation.

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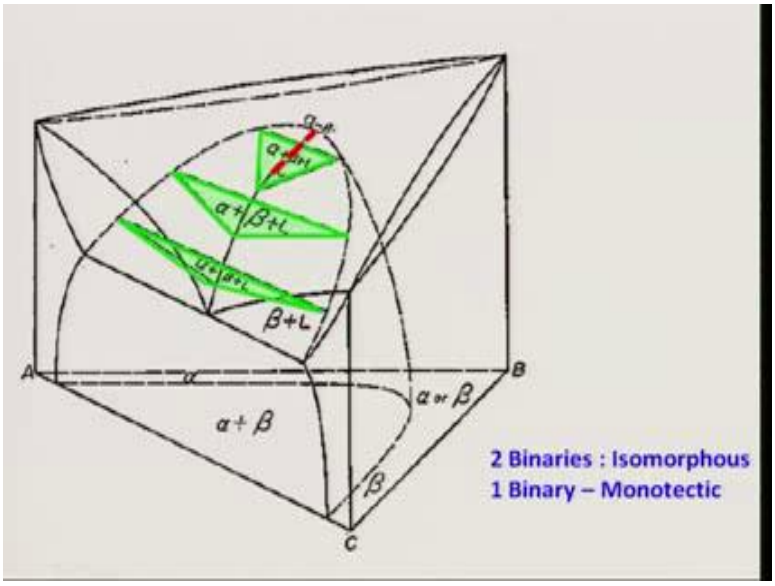

Finally fourth one, you can have two binaries as an isomorphous, and one binary as a monotectic system correct?

So, out of the 6, I am showing only to you, 4 different types, or rather 3 different types or 4 actually, not 3. Isomrphous, isomorphous eutectic, isomorphous plus pretectic, isomorphous plus monotectic, so, that means, what, we can generate this 3 phase equilibrium, or we can have the 3 phase equilibrium, under different different reaction conditions. And that makes us that you know, the chapter on this will be a very very long chapter. One has to, one has to discuss every situation in the text, in the lecture, then it will take a long time. So, we cannot do that. So, what we will do we will take a system which is more generic, that is the system which has one of the binaries as isomorphous type and other two binaries AE eutectic types, correct? So, let me just go the board and tell you how it will look like.

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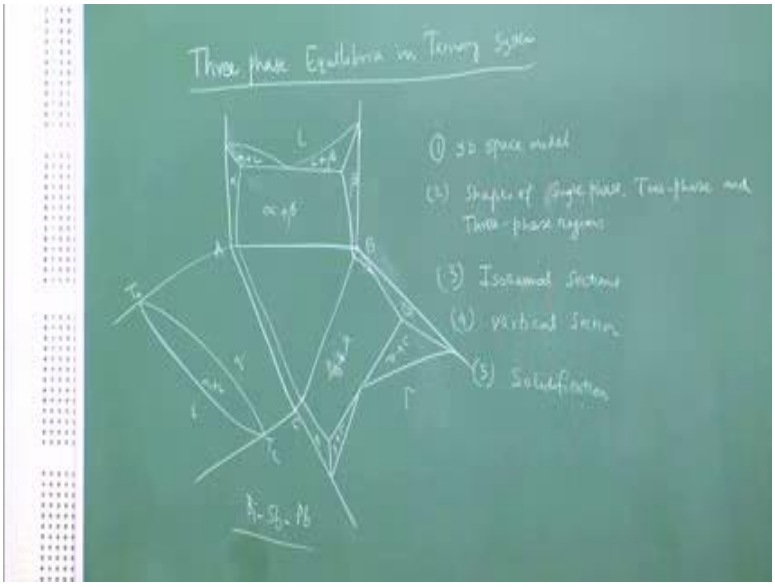


So, suppose this is my, this is my Gibbs triangle. So, this is one binary, this is another binary, and this is the third binary, correct? As I said, one of the binary will have isomorphous; other two binaries will have eutectic.

So, this is about this second one, third one will also be eutectic. So, this is what is the situation, we want to discuss. And as I said told you that this is a very generic situation that is why we will discuss in detail. So, what all we will discuss here? So, this is the, you know, 3 binary phase diagram. So, we need to develop ternary here, and then go for

ahead, different aspects of the ternary phase diagrams. So, first thing we will discuss is the 3D model, 3D space model that will tell us how this phase diagram will look like. Second thing we have to discuss is the different shapes of different rejoins. Shapes of single phase, 2 phase and 3 phases rejoins. Third thing will discuss about isothermal sections. Fourth is vertical section, and fifth is solidification behaviour.

So, we are going to do one by one, but first thing I would like to impress you upon is that you know there are phase diagrams, which follow such a kind of things. Like bismuth antimonia and lead. Between lead and bismuth, and lead and antimony, lead and bismuth, lead and antimony you have a eutectic phase diagrams, but bismuth antimony forms, isomorphous. So, ternary phase diagram will be, will be what I am going to discuss will have lot of similarities with this phase diagrams. So, there are many such examples. So, now, you know how this, how this, space model, well yeah, well before I do that. So, this slide will tell you.

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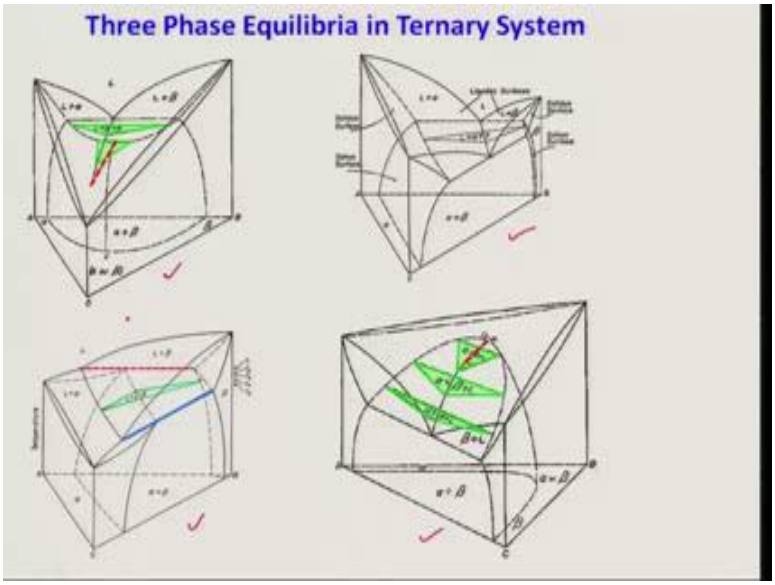


This is the one, with 2 isomorphous, 1 eutectic, 2 eutectics, 1 isomorphous, 1 peritectic, 2 isomorphous, 2 isomorphous, 1 monotectic systems.

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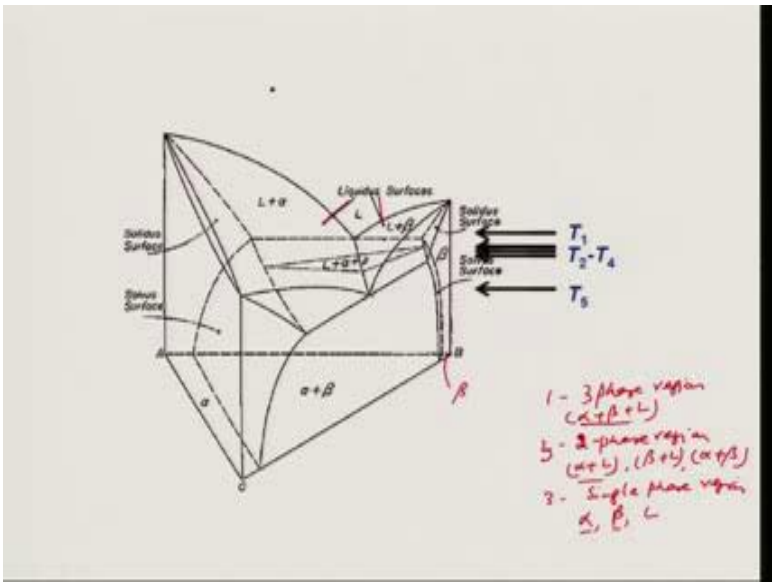


So, let us now discuss about the ternary space model, of the system which I have been telling you. So, I will just try it to keep it things nicer, I am going to use draw it from the, from this chart, what I have drawn myself. So, let me just draw it on the right side. So, that you understand it nicely, the 3D space model so.

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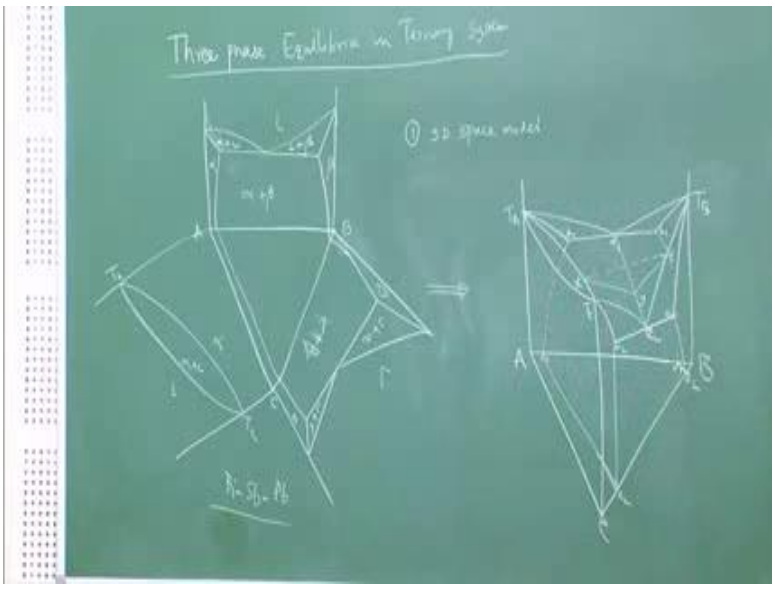


First I have to draw; little bit I have to distort this triangle to show you the 3Dimensional projections. Otherwise you cannot see it. So, first is that, between A and C you have isomorphous system, you can see here between A and C there is an isomorphous system.

So, this is t a, suppose. So, this is T C, now between B and C there is a eutectic. So, this is the eutectic, and this eutectic is marked as E2. And then between A and B there is a eutectic. Please follow the way I am drawing. So, that you could understand it nicely this little bit. So, this is my E1. So, now, I remove the other parts, as you see here this is the ternary space model of the phase diagram. So, now, one can actually write put different numbers, this is suppose C1, this is D1, this is A1, this is B1, and similarly this is A2 B2 C2 D2 correct? So, we will connect these two points, why you are connecting? One thing you have probably seen that, I have kept Alpha Alpha Alpha same, correct? You could see here, this is Alpha phase between A and C, is same as the Alpha page between B and C, they are sharing the corners.

Similarly, Alpha phase here also sharing the corners with the c. Beta is sharing the corners. That is why we can join these points, this is basically Alpha zone, similarly we can join these two points - this is my Beta zone. Now, you know one thing you have to understand here, because you have eutectics here, so you need to know where these eutectic lines in the ternary goes, correct? So, let us connect this. And we can write down XYZ. So, you basically the point I am trying to make is that, ternary equilibrium between Alpha, I am not mark the phases here, rather it will be a complex, between Alpha Beta and liquid, has a triangular shape, and this is the tie triangle which we are discussing, which we are going to do much more in the next (Refer Time 19:18). So, this is Tb. I hope this you can draw yourself. Initially when you start drawing, it might be looking little bit complex, but you should try drawing yourself. So, we have generated the ternary phase diagram, from these binaries, basically as you see here.

So, now let us go to the slides, because slides are more important. Let us go to slides and discuss. So, as you see here these are the liquidus surfaces, this two, and solidus surface is also shown here, and this is Alpha, this is Beta, this is Alpha plus Beta. What does it mean? Basically at temperatures lower then the eutectic temperatures E2, you have Alpha, Alpha plus Beta, and Beta 3 phase sheets in the bottom. It will be clear much clear what I discuss this.

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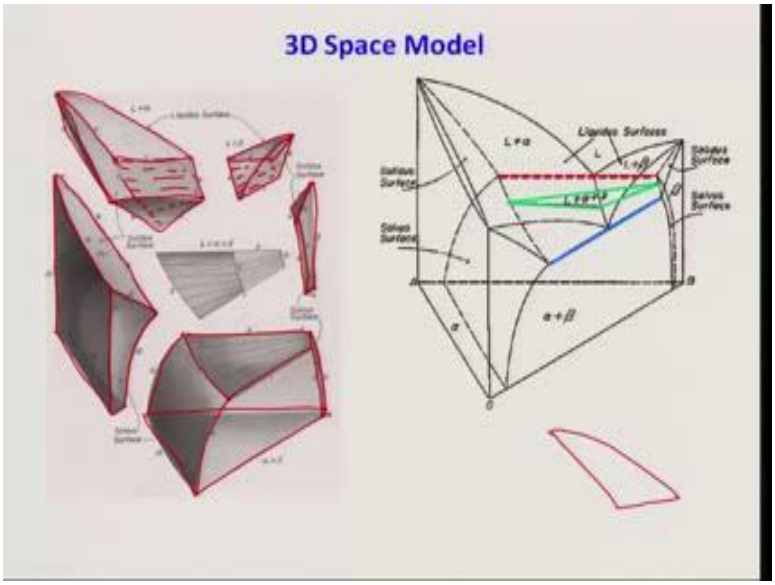


Now, upon discussing, this 3D space model, which is again shown here, let me discuss about the shapes of the different different, you know zones, different things. So, what we have here basically, there is one 3 phase region, Alpha plus Beta plus liquid, and there are two 2 phase zones, Alpha plus Beta, Beta plus liquid, and Alpha plus liquid. Ok? So, let me write down. So, you have one 3 phase region, which is Alpha plus Beta plus liquid, and you have two 3 phase, two phase region, two 2 phase? No 3, 2 phase region, what are they? Alpha plus liquid, Beta plus liquid, and Alpha plus Beta, right? And there are 3 single phase region, what are they? Alpha Beta and liquid, you need to see each of these shapes of these things. At least, we need to see Alpha Beta, Alpha plus liquid, Alpha plus Beta plus liquid, then it will be clear to you how the things look like.

So, now again the 3D space model is shown on the right side, as you see here 3D space model is shown on the right side, what you see here? You see that, you know the triangle which is shown here liquid plus Alpha plus Beta, is what is known as the 3 phase equilibrium zone, and it basically remains same. Here also at the bottom also will show it will remain the same. Whenever, wherever, till the temperature at which the 3 phase equilibrium exists, you will have the same things. So, that is the, let us now see what is the Alpha looks like. Alpha looks like this (Refer Time: 22:24) you can see here. I have drawn in the last class also. This is the one; I do not want to draw it on the board, because this will consume lot of time. So, this is what that is, and then you know, we have the signature of these isomorphous, at the top, and this is my Alpha, correct, clear?

You should try to draw and see that. So, Beta will be smaller than that, you can see here this is Beta, this is like this, this is like this, correct? This is the Beta.

So, these two are my Alpha Beta zones. Then what about the Alpha plus liquid? Alpha plus liquid is this zone, you see here, it although it looks like, from the perspective, it looks like this kind of stuff, like this, but it is not, ok? Anyhow so the way it looks like is, this is what is I have drawn it, just now, and then you have this zone, this zone, correct? Is quite complex. On the other hand liquid plus Beta is much simple. it is like a pyramid, but angular. These are all known as rule surfaces, why? Because you can draw the tie lines, you can see the other tie lines are dotted dotted line tie lines on.

You can join the liquid, two phase zones with their tie lines, because it is a liquid plus solid. Similarly here also you can join two phase zones with the tie lines correct? So, that is how it shapes then Alpha plus Beta is easy, you can see here how it looks like, is just like that. it is shown very clearly. This is, this is this part and that part downward part is also shown, correct? And then the top one is shown like this, but at the bottom you see there is a triangle remains, now this triangle is Alpha plus Beta triangle, On the other hand, the most important zone which I have shown you at the last class is the liquid plus Alpha plus Beta, that looks like this.

Basically it looks like a triangle, you can see no, this is a triangle. Now as you know. What is of the each of this triangle is basically telling with the compositions of the liquid and Alpha and Beta, and as the temperature goes down, the compositions also do gets changed, and because of that, what you generate is basically is a series of triangles, and this triangles, we can actually draw tie lines also, these are the triangles.

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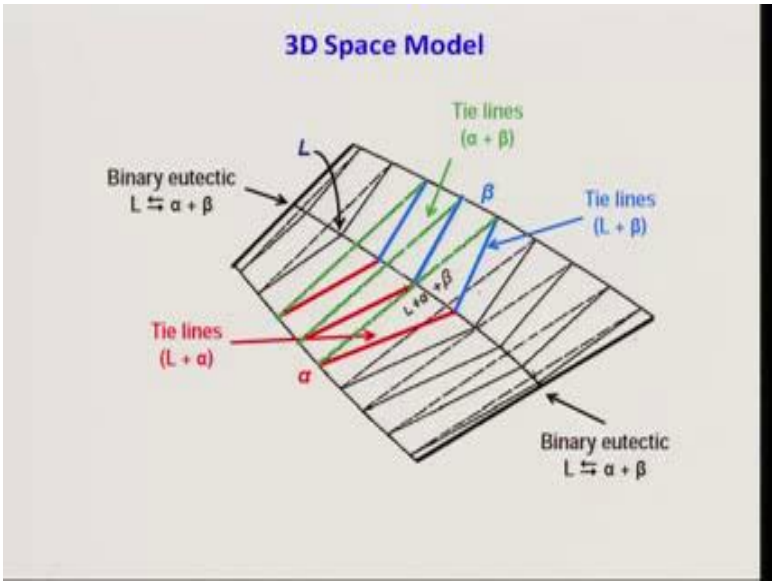


Each of this triangles are shown here, and one can actually draw this tie lines inside that. Let me just go back to this picture, you can see here this are the tie lines, we have drawn right? These are difficult to grasp or understand, but once you have a feeling of this, the 3Dimensional space, you can actually realize it, that it looks like that. So, it is nothing more than that I can do, other than showing you the picture and drawing it on the board, but you have to yourself have to practise it.

So, these are the triangles, and you have a, this end you have binary eutectic, also this end you have binary eutectic, they are joined, correct? And this is the tie lines between Alpha plus Beta, or liquid plus Beta. So, these dotted once are between Alpha plus Beta, and these solid once are between liquid plus Beta, and this one is Alpha plus Beta liquid, ok? There are 3, three different colours are shown. So, this one is, this one I am showing you is basically, liquid plus Alpha, this one which is blue colour is basically liquid plus Beta, and this is Alpha plus Beta. So, therefore, I have shown you all the 3 zones.

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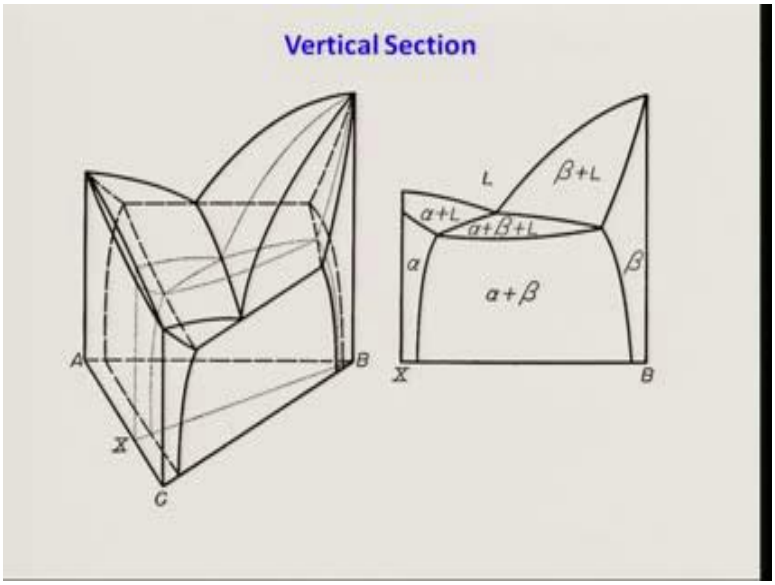


Now, actually I am going to discuss about a vertical sections and the certifications of the other things in the next class, because this requires further discussions. So, of this space model, but anyway I am, every time I am going to discuss with the space model. So, you should better concentrate on the space model carefully (Refer time: 26:56) section (Refer Time: 26:57) your isomorphous section will discuss today.