Phase Diagrams in Material Science Engineering
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Lecture – 45
Ternary Phase Diagram and Tie Line Construction –I

So, students we have been discussing about ternary phase diagrams and I am discussing the basics of the ternary phase diagrams. In the last class, I told you about ternary tie lines and ternary tie triangles. So, today we are going to discuss more on the, the ternary tie lines, especially details of the ternary tie lines, I will talk about it and in addition to that I am going to tell you also the different sections of the three-dimensional ternary phase diagram, which normally we see.

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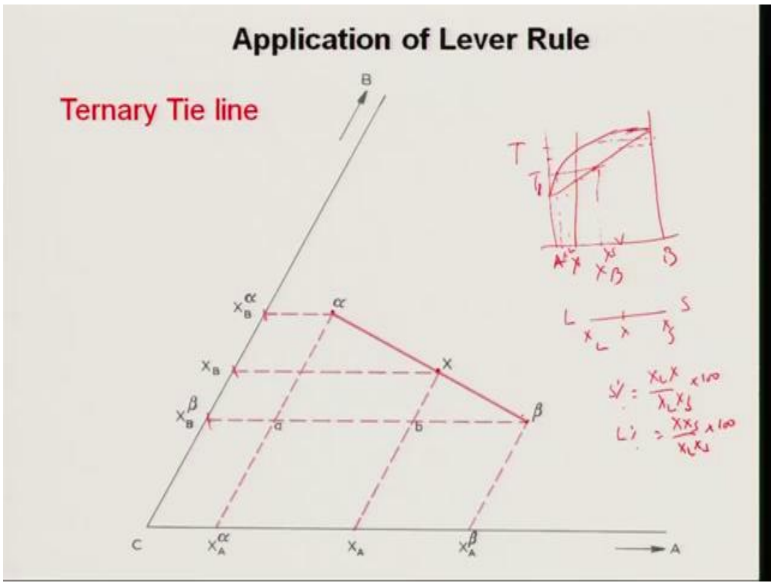

Well, you know, tie lines are what? In a binary phase stress diagrams, as I told you, tie line connects liquidus with the solidus, curve basically. So, as I shown in this plot, this is a binary phase diagram. You can see, here it is connecting the tie line at T 1. It is connecting the liquidus with the solidus and so, in ternary the concept remains same. So, if I suppose have a ternary tie lines, it can be also connecting to solid to solid curves also. There is nothing, nothing sacrosanct about, that it must be only connecting a liquidus and solidus. The two, saw, the two curves, which connects one solid to other solid can also be a tie line. So, I am going to show you that first.

Suppose we have a alloy composition given by point x, and this alloy is then separated into two solid phases, alpha and beta, correct. So, if I connect these two, these three points' alpha and beta through x, then I get a tie line. And now, I showed you in the last class how to use this tie line to measure the volume fraction on the phases alpha and beta, just like in a binary system we can do that only thing we need to be careful about, that we need to draw parallel lines with respect to, respect to BC or AC here through x alpha and beta points.

And then, wherever these tie lines will intersect, the, this line, the sides of the triangle, sides of the Gibbs triangle, we can actually use those points to measure the volume fraction of phases, as simple as applying lever rule. So, this is when you have two phases present in a microstructure.

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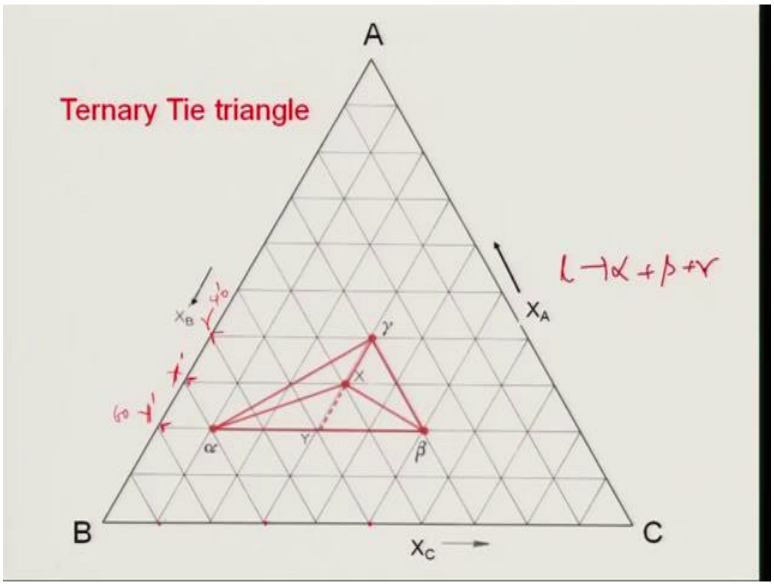

When you have three phases presents in a microstructure then you need to use what is known as ternary tie triangles and concept is again similar, but little bit different.

So, suppose I have alloy composition of x, which is sitting in the center of this triangle alpha, beta, gamma and this means, that alloy composition x is separated or physically undergone a phase transformation, which is lead to, which has led to formation of alpha, beta, gamma phases, just like eutectic reaction, L going to alpha plus beta plus gamma, correct, same thing. So, this alloy x has undergone such a kind of a reaction where three phases has formed, alpha, beta, gamma and whose compositions are given by these three points. So, this is what is known as ternary tie triangles.

Now, to measure the volume fraction of phases for these we have used the unique strategy. I told you we join the point x with gamma and extend these to the sides of alpha and beta, the line joining alpha and beta points. So, this intersects at point y, correct. So, now we can measure, basically, volume fraction of gamma and volume fraction of the fictitious phase y using these as a tie line y, x and gamma. So, once you do that we will come to know volume fraction of gamma and volume fraction of the y. So, volume fraction of gamma is nothing but x, y divided by the line gamma y. On the other hand, volume fraction of y is given by x gamma divided by the line y gamma. This is very simple because these are parallel line with respect to the AB. So, that is for, that is set for.

So, then this fictitious phase y, y you have measured now is there and getting separated into two phases alpha and beta and we can then calculate the volume fraction of alpha, beta by knowing the composition of alpha, y and beta, that is what I told you.

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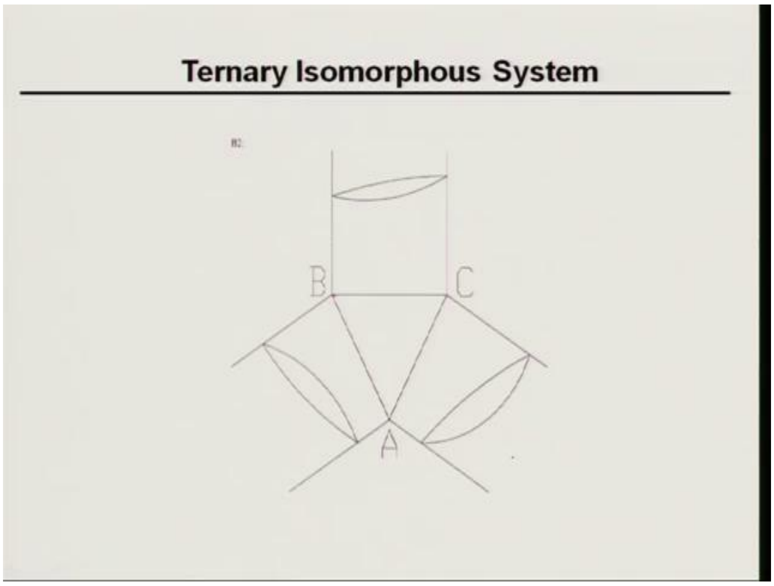

Now, in this lecture we are going to tell you what are the rules and regulations for the tie lines. I think before that let me just, you know, try to discuss you something about what is the real phase diagram means, that is what we started. Let us first consider ternary isomorphous system and we will have extensive discussion on these for the next several lectures.

So, we have a system like ABC, three components and in which I have shown this Gibbs triangle, ABC. Also, we have shown you the particle lines coming out from these three points, B, A and C in such a way, that for the system AB, system BC or system AC, there are three binary systems, they are all having isomorphous phase diagrams. So, that means, A and B also forms isomorphous phase diagram, A and C forms isomorphous, B and C also forms isomorphous phase diagram. So, basically if that is the case, then the ternary phase diagram will also be isomorphous type.

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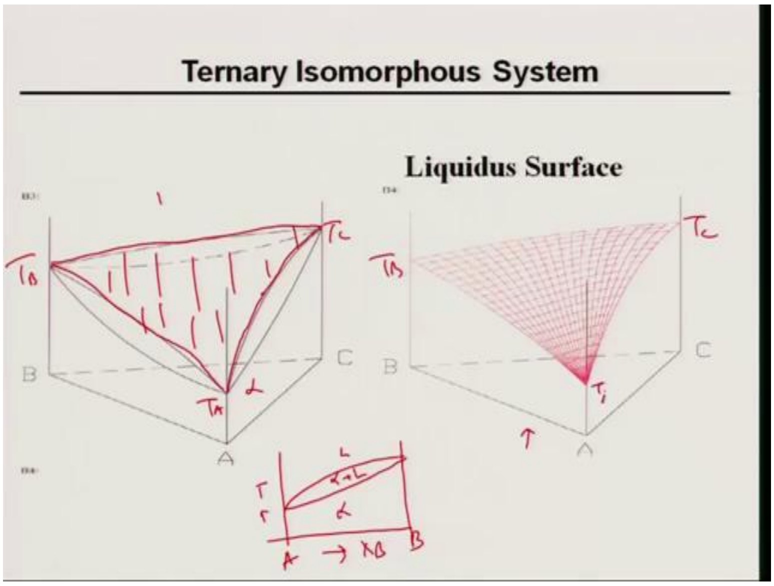

The way the ternary phase diagram will look like is like this. Basically, it is again looking like a corn shell like this with two surfaces, (Refer Time: 05:48) shown two surfaces, forming the phase diagram. This is of two lines and two curves. In the binary we have two surfaces, the top surface is known as liquidus, bottom surface is known as solidus. So, this is a top surface. You see here, top surface is like this, I am only drawing the top surface for you. So, this is the top surface, this is a liquidus, ok. One can actually mark it, this is the liquidus and bottom one is solidus. So, there are two surfaces. Inside that we have liquid plus solid, above the liquidus we have liquid, above the solidus we have solids and in between that we have solid plus liquid.

Again the same analogy can be bought from this binary system A and B, this is exactly that. So, what we have done, because it is a three-dimensional plot, in a ternary system we have to use the concept called surface. So, there are two surfaces, correct, and now on the right side, I am showing you the liquidus surface profile, that is how the liquidus surfaces look like. And here, actually C has a highest melting temperature, B has the medium or intermediate and A has the lowest melting temperature.

So, that is why, the whole thing is looking like is going down towards A in this, in this diagram. You see, here whole thing is looking like line; it is going down in the A. It is not like that, it is a surfaces basically, which connects the three melting points A, B, C and this is T C, this is T B and this is T A, correct, that is how it look like.

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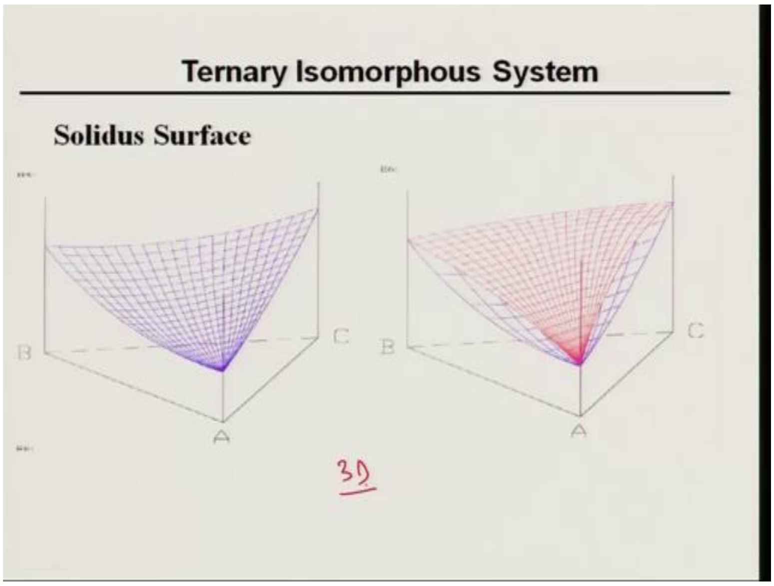

Similarly, solidus surface will be also looking same. Basically, the way you are seeing a solidus surface is just like a curved surface, going out of A and moving towards B and C, correct. Now, you join these two together, you get a three-dimensional phase diagram, very, very clear, very, very clear. So, if you are not able to see it properly, if you are not able to see it properly or see it means you are not able to think in terms of three-dimensional diagram, just close your eyes, try to think about. It is, basically, like a corn shell, take a corn shell, the two surfaces or basically, you can take a, you know, instead of corn shell you can take this shells available in the sea surface. They look like an elliptical surface, but they are bounded by two planes. So, that is exactly same thing as a ternary isomorphous phase diagram.

Now, you know, as you have, as you have rightly thought about it. So, if you want to discuss, this is very easy to conceive, very easy to interpret it, but the phase diagram can be very complex also and it can be consisting of more than three phases, as you have seen four phases equally as possible in a ternary system. So, in those cases the diagrams will have this complex steps and in many times, it is very difficult to conceive, very, very difficult to conceive the, the steps of these diagrams in three-dimensional position, three-dimensional actually section or 3-D model; this is actually 3-D model, right. So, therefore, it is always important, that we make easier things. So, one of the easiest thing is to use projection, ok.

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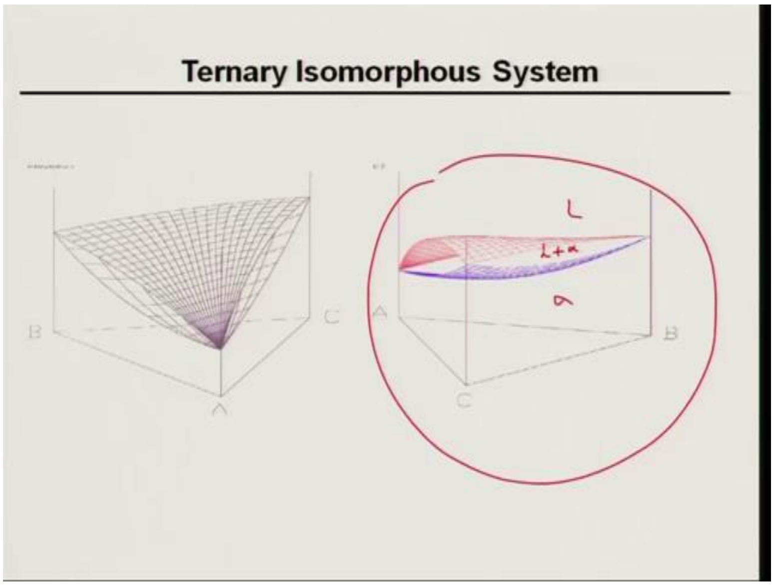

So, there, here I, again I am showing you this, this plot, is very, very nice. You can see even how these two surfaces looking like. You can see inside, that is, you have liquid plus alpha, liquid and alpha, three phases are present.

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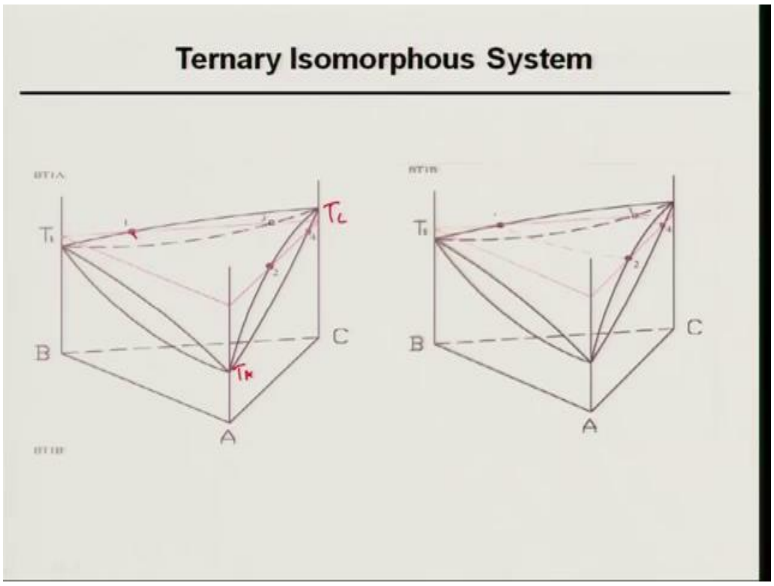

So, as I said, we need to use the sections, correct. So, what are all different sections we can use? We can use sections; first thing we can use is a isomorphous section. What is isomorphous section? Well, as it says, isomorphous, sorry, isothermal section, not isomorphous, isothermal means sections, that is taken at a fixed temperature. So, as this diagram spans from, with maximum temperature T C to minimum temperature T B, T A, T C to T A, as you see here. So, therefore I can take ternary, the isothermal sections at different temperatures to show you, that what the, how does it look like.

This I am showing you two pictures here. Let us, suppose, I want to take a isothermal section at temperature T 1. So, what I do? I draw a triangle; I simply draw a triangle at a temperature T 1 and then, wherever this triangle cuts these two surfaces, that is, become my isothermal sections, correct. So, as you see clearly here the triangle, which is shown by red color is cutting the solidus and the liquidus surfaces. So, it is called, cuts a liquidus surfaces at these two points, 1 and 2; it cuts the solidus surfaces at this point 3 and 4, correct. I hope, because this is, this is why the visualization is very important. In binary system you do not need to visualize much because they are all two-dimensional structures altogether, but here you need to visualize very, very, you know, nice way or very, very carefully, I would say.

So, as you see here, this section, which is parallel to this ABC triangle or Gibbs triangle, taken at a temperature equal to T, T equal to T 1, that is what is the temperature. So, I have drawn a triangle at temperature T 1, which is parallel to this isothermal sections, parallel to these, you know, Gibbs triangle, that is why, it is a, you have taken triangle. Now, this triangle, as i said, as cut the, cut the surfaces into four points. Obviously, by it can also cut only two points. It depends on how you draw the triangles, why you take the section.

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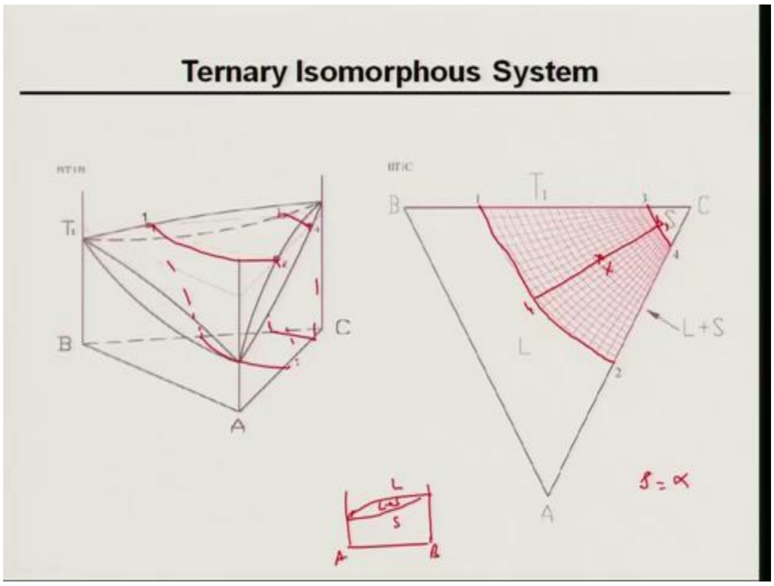

So, if I, if I, then, if I then do that, if I then project this whole thing what I will get? I will get these 1 and 2 points, you see, 1 and 2 and 3 and 4. So, this is what is shown here. And you see, this is C, this is B, this is A. A is a lowest melting temperature, C is the highest melting temperature and so, because this is a section at T 1 and I know, that is, A has the lowest melting temperature.

So, therefore the line, the, these, this will basically, this is a, this is what? This is separating three phase phases or three sections of the phases nicely. As you see here, this is a liquid, this is for liquid plus solid, this is solid. I always marking S equal to alpha, solid equal to alpha because we always mark or use, you know, alpha has the Greek letter for the solid phase. So, what I mean to say is that this is exactly same as a binary system: liquid, solid, liquid plus solid. AB seems exactly the same thing here. You see, here, this is the liquidus surface projection, the solidus surface projection; this is a liquid, liquid plus solid and solid.

So, now if I draw any line, any line, which connects liquid into solid, this is a liquidus surface projection, the solidus surface projection, right, you have taken at a temperature T 1. So, basically, because these points are actually, this you can see here, you can project it here, you can project it there, you can project it there, you can project it there, that is what you get, that is what you get. This is exactly same thing on the triangle. So, I, if I connect these two curves now, not surfaces anymore because we are projecting on bottom, to the bottom surface, to the Gibbs triangle, they will become curves, and they will no longer become a surface because it is a two-dimensional section.

So, if I draw a line like this, it connects liquid to solid that is a tie line. Now, this tie line is same as binary tie line. I can use this tie line to measure volume fractions. Suppose this is my fulcrum, this is L 1, this is S 1. So, liquid is, volume fraction is x S 1 by L 1 S 1, exactly same. The moment you know the composition of x l, L 1, S 1, I can calculate the volume fraction of phases very easily. So, these are the tie line we draw. Now, one can actually draw many sections.

Suppose, here actually I am drawing a section at T 2 and you see, T 2, this is shown by green, green triangle, how it will look like? Again, here connections are shown, but not many visible, but this is what it will look like.

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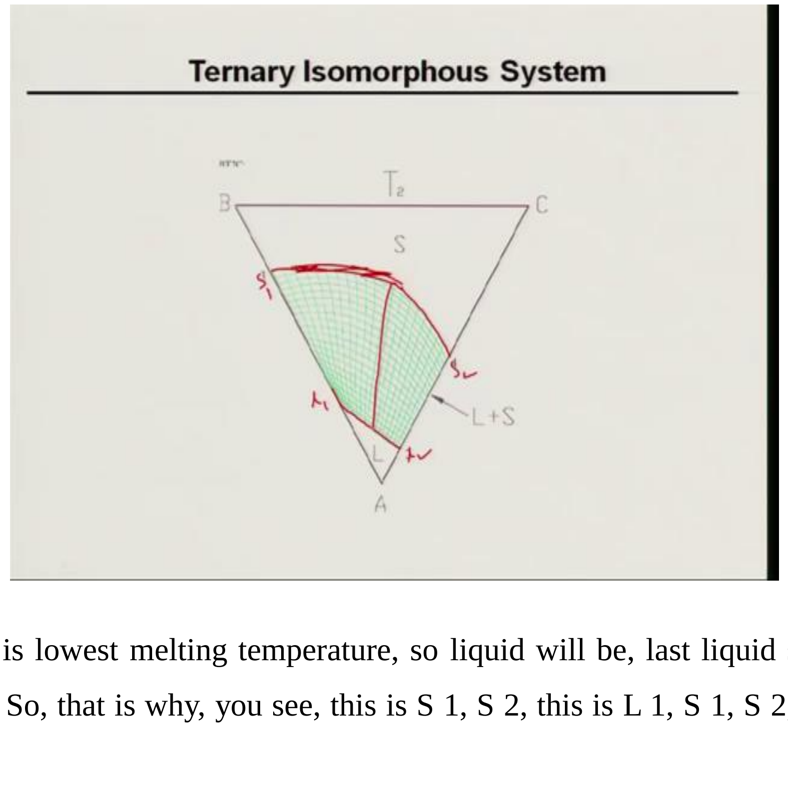

As simple, A is lowest melting temperature, so liquid will be, last liquid solidified will have A reach. So, that is why, you see, this is S 1, S 2, this is L 1, S 1, S 2, this is L 1, L

2, S 1, S 1, S 2, sorry, oops, anyhow, So, this is, these are the two surfaces. Again, these lines, which I am joining, are tie lines. So, one can actually do such a kind of things. We will go back to this later, such a kind of things, such a kind of projections one can take and do the analysis.

So, now as you have seen, this is a tie line, so obviously, the tie lines will follows certain rules and regulations and we seem to discuss about that. I will discuss probably all the, there are 4 or 5 rules, which one is to know to understand these, these, how to draw tie lines in a ternary section. So, I am going to discuss two rules for this lecture and next lecture, I will discuss another two or three rules.

So, the 1st rule says, that the 1st rule or most important rule is, that if a two phase region, two phase region stretches from one binary to the second binary, I will explain each and every point to you, if a two phase regions stretches from one binary to other binary, tie line will gradually change from one binary to the other binary that is what is the rule. So, what is that mean? In this case, suppose I have drawn, in this case I have drawn. So, tie line actually extend or stretches from one binary to the other binary tie line is, stretches from one binary BC to other binary AC, that is what you can see if they are stretching from one binary to the other binary. Now, it is, says, if that is a case, then tie line, the binary tie line is this one which is on the binary. Similarly, this is also binary tie line, correct.

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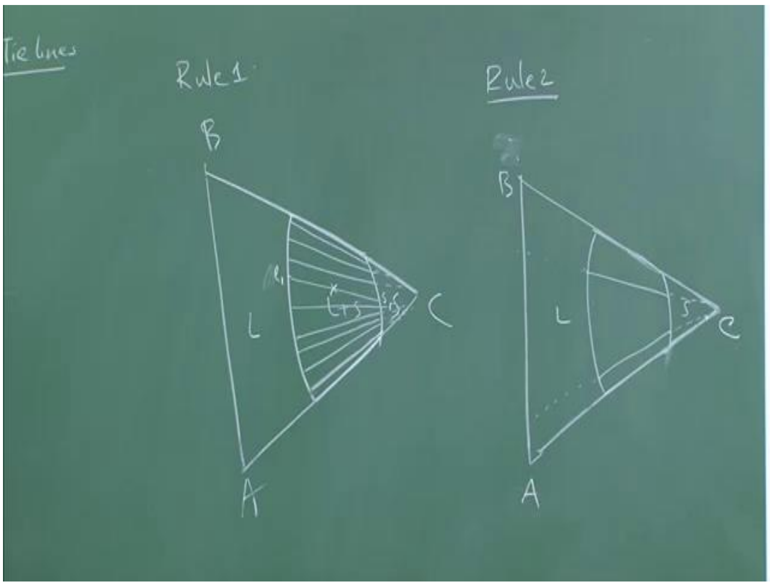

So, as these are the two binary tie lines, so what is a, what is the aspect? These are the two binary tie lines. It says that the tie line will change gradually from one binary to other binary. So, that means, that let me just go to the board and explain you that is easier. So, that means, that I will try to draw the same thing here. Last point is A, yes it is A, C, B. So, liquid, solid and there is a liquid plus solid.

So, this is the binary tie line. It says that binary tie lines will keep on, rotate or keep on, casually change, that is what will happen. So, the change of the binary tie line orientation will be gradual from one binary end to the other binary end, that is what is the rule says, because these two are the binary tie lines and inside this, actually, ternary tie lines. So, if I take one simple tie line L 1 S 1 inside. So, this one is keep on changing the rotation to match one end, one binary BC, other end, another binary AC, that is what the rule 1 says. This is the rule 1.

So, rule 2 is much easier. Rule 2 says, in general, in general binary tie lines, it extend, will meet, in general a binary tie line extends, if I extend this binary tie line, it will meet the corner, it will meet the corner. See, this is the binary tie line or let me just draw it. So, this is my binary tie line, this is my binary tie line, if I extend them they are all going to meet the corner C, but that is not the case for ternary. None of these ternary tie lines are going to meet the corner. So, it is only the binary tie lines, which can meet the corner if you extend. Now, this ternary tie lines will extend, they never meet any corners. You see here, it is meeting somewhere else, not at the corners.

This rule has an exception, exception is, that when this phase solid has a very low solid solubility of the component C, then this can meet at point C. Basically, what does it tell? This is a tie line, so these points if it extends and meets that will be solid solubility of the solid for the component C. Now, only in case the component C has virtually no solid solubility in solid phase alpha, then only this ternary tie line can meet the corners, that are now exceptional case, exception is not the rule. So, rule is, that when one binary tie line extended it can meet the corner or when another binary tie line extends to meet the corner, but none of the ternary tie lines extended will meet the corners of the Gibbs triangle; that is what is the rule 2 says.

So, again I will, before I end this lecture I like to reiterate, that tie lines connects liquid and solid surfaces which are taken at a particular temperature, T 1, T 2 or T 3 or T 4, depending on the whatever temperature you want and they connect because they connect these liquidus, liquid L 1 in to surface, sorry, curve, which is projection on the surface from the three-dimensional model. Also, it connects this one and with this solid projection because of that it tells you, that they are actually looking like a binary tie lines. We can use them like a binary tie line if I have a composition x. I can actually calculate volume fraction of a liquid, volume fraction of solid at the particular temperature for this, using this tie line.

Similarly, actually, actually I can actually see that there are 2 rules. The 1st rule, there are 5 rules actually; I am only listing 2 rules here. First rule says that the tie line will continuously change its orientation from one a, one binary to the other binary. Second rule says is, that only the binary tie lines extended will meet the corner. Ternary tie lines will never meet the corner except when the solid has low solid solubility in component C or component A or component B depending on which you are drawing and in this case, it is component C, that is, that is, what then this ternary tie lines will meet the corners. So, that the other 2 rules, other 3 rules rather, I will try to discuss you in the next class and subsequently, I also tells, tell you the, tell you the particle sections, another sections, not particle section I am going to discuss you the, in a projections of a liquidus and solidus surfaces.