Materials Science
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Lecture 17
Phase Diagrams

We were talking about the equilibrium in phases which are present in a system and we looked at the Gibbs's Phase Rule, saw the application of the Gibbs's Phase Rule to one component system that of iron. Today we shall move further and look at system of two components. There are systems with three components, four components. We shall not go to that. We shall restrict ourselves to component systems. Most of the alloys we shall be able to understand with that.

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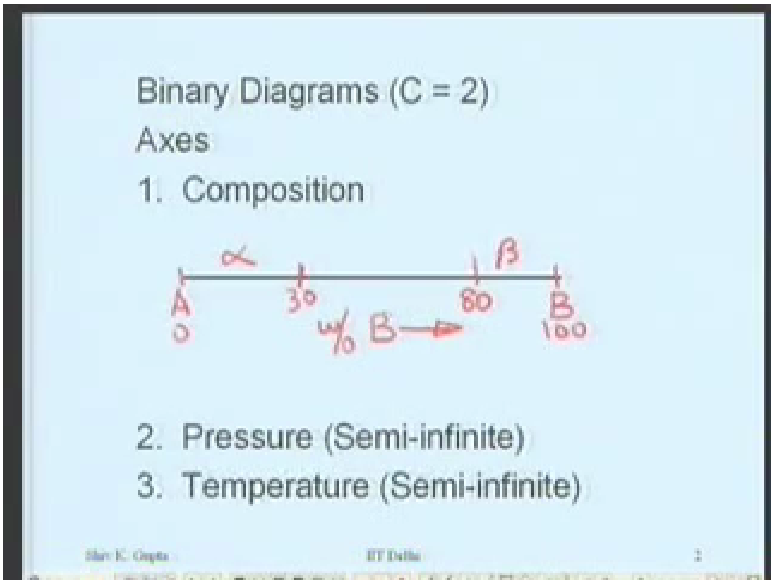

Binary Diagrams (C = 2)
Axes
1. Composition

2. Pressure (Semi-infinite)
3. Temperature (Semi-infinite)

In a two component system, is called the binary diagram. In a binary diagram, component equal to 2, the variables going to be composition variables and the two thermodynamic, variables pressure and temperature. Now to represent these variables on the two-dimensional diagram, that is on a plane of paper or the blackboard, see what do we do. There are two components, composition, normally are shown by a finite axis with 100 percent one component here and 100 percent of the second component there.

In between we have the variation of the amount of B going from 0 at 100 percent A to 100 percent at B. This is a finite axis. Now I have a composition variable for every phase, that is how we count it, P into C minus 1. Composition of phase I need not be same as composition of phase II, need not be same as composition of phase III. What was a situation in a unary component? In the unary diagram we had all phases having the same composition, same component, right?

So there are more than one phases, do I need more axes than these? Instead of one axis can I have, will I have to use two axes at two phases? If there are three phases we have to use the three axes? No. I can do with one axis alone. When one phase in equilibrium, second phase will not be there. Equilibrium has been defined where the free energy is at its minimum. System would stay in that state where the free energy is at its minimum.

If (compo) phase I is present, from 0 percent B to 100 percent B, this I have written W oblique 0, W percent is weight percent. Normally engineers work with making alloys, measure 100 grams of A, 50 grams of B, mix them, find out what is the proportion. So we call it weight percent. Can we do, the researchers are working, they like to work with 100 atoms of A and 50 atoms of B, so they put atomic percent, they write A oblique O. It is possible to convert weight percent to atomic percent but mostly our diagrams will be with weight percent.

Now let us say there are more than one phases present in the system and let us say at the given temperature and given pressure, whatever that value may be, phase I exists from 0 percent B to 30 percent B. Let us call t phase alpha. And beta phase, the second phase exists from 80 percent B to 100 percent B. Where 0 percent to 30 percent alpha is existing, beta cannot exist because that is the equilibrium. Where beta exists in equilibrium, alphas cannot exist.

Maybe in between 30 and 80, both of them exist. So it is possible for me to represent the equilibrium between more than one phases of the same axis at a given temperature and pressure. So one axis can do my work, composition axis and normally the convention is you have alphabetically the components are written, A here, B there. Let us say for example, silver and copper. Silver, you write Ag, that will be on the left. Copper, Cu will be on the right.

Or you write let us say copper-nickel diagram. Copper, Cu start is here and nickel, Ni is there. So alphabetically they come in that order usually. Then we have the thermodynamic variables, pressure and temperature. Pressure can be 0 when perfect vacuum, that can go to infinite. So it is semi-infinite axis. While compression was a finite axis, pressure is semi-infinite axis like I showed in the unary diagram.

And temperature is also semi-infinite axis, 0 kelvin to it can go to infinite. So I have three axes, one is finite, other two are semi-infinite. I must have a three-dimensional diagram for the three axes. To represent this on a plane like that of a paper or the blackboard or the screen, it is not convenient. So what we do is we take a section of this three phase diagram or three-dimensional diagram.

The diagram is three-dimensional but we take a section of it. We take a section either at a constant pressure or we take a section at a constant temperature. It becomes a two-dimensional figure. The one which is taken at a constant pressure is called isobaric diagram. The one which is taken at a constant temperature is called an isothermal diagram. Okay. That is what we do.

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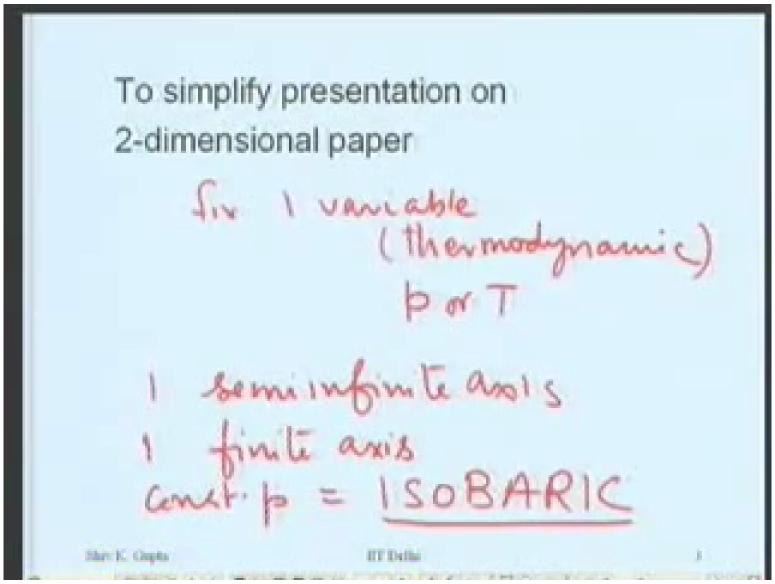

To simplify presentation on
2-dimensional paper

fix 1 variable
(thermodynamic)
p or T

1 semiinfinite axis
1 finite axis
const. p = ISOBARIC

We fix one variable and the most comfortable variable is one of the thermodynamic variables, either pressure or temperature. So I shall be left with one semi-infinite axis and one finite axis. It shall become a very comfortable diagram to look at. Most of the systems, material systems engineers are working are at 1 atmosphere except when you are taking about some reactions taking place in the reactor vessel at a particular pressure only.

Most of the times we are working at 1 atmospheric pressure, temperatures could be varying. Okay. We shall look at the diagrams at constant pressure, isobaric diagrams. Okay. Constant pressure becomes isobaric diagram.

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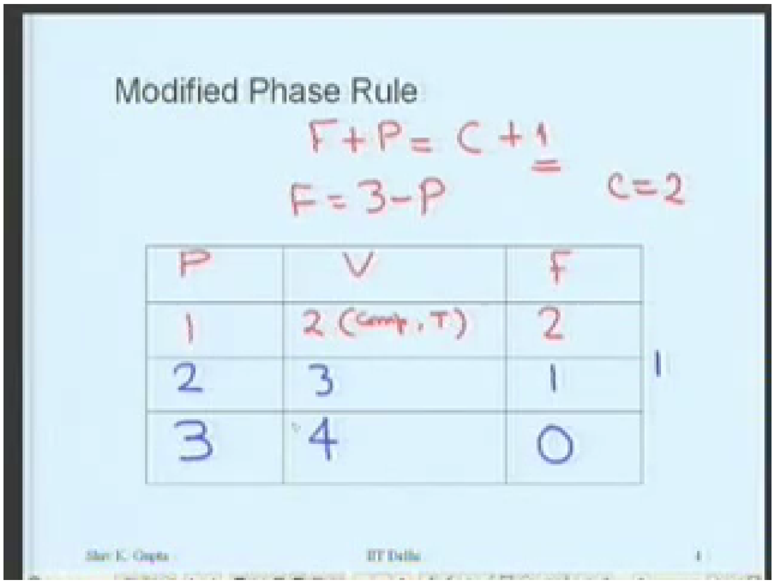

Modified Phase Rule

$$F + P = C + \underline{\underline{1}}$$

$$F = 3 - P \qquad C = 2$$

P	V	F	
1	2 (Comp, T)	2	
2	3	1	1
3	4	0	

Now while doing so, I have fixed the pressure at 1 atmosphere. In other words, we can also say that I have fixed 1 degree of, or exercised 1 degree of freedom in the system by choosing one variable that is the pressure as 1 atmosphere. So I have exercised already 1 degree of freedom. So my modified phase rule for the binary system which is represented in two dimensions will be, recall your phase rule, this 2 has become 1 now because I have exercised 1, I have exercised 1 degree of freedom. Degree of freedom has become one less, so that has become C plus 1.

That 2 was coming for pressure and temperature, I exercised pressure, right? So it is a modified phase rule. Now in a binary system C is equal to 2, so F becomes, C plus 1 is 3, so it become 3 minus P. And let us look at here number of phases, variables and degrees of freedom.

“Professor-student conversation starts.”

Professor: If I have only one phase present in the system, how many variables shall I have?

Student: 1.

Professor: 1….?

Student: Because 1 is pressure item.

Professor: Number of variables in a system are pressure and temperature and composition variables. Since it is one phase, there will be one composition variable. And out of the pressure and temperature, I have already exercised pressure as 1 atmosphere, so I am left with two variables. And the two variables I am left with are composition and temperature. So how many degrees of freedom do I have? 2. 3 minus 1 is 2.

You can change both composition as well as temperature within the boundaries of the system or boundaries of the phase diagram, alpha phase or the single phase whatever is there shall remain in equilibrium. If I have two phases present in the system, how many variables do I have?

Student: 3.

Professor: 3. Out of which two will be composition variables and one will be the temperature. Okay. And degrees of freedom I have is……?

Student: 1.

Professor: 1. Degrees of freedom I have is 1. That is out of the three variables in the system, composition of the phase I, composition of the phase II and the temperature. I can exercise now to fix any one of them if I want to see the equilibrium between phase I and phase II. If I fix the temperature, composition of phase I and the composition of phase II will be fixed. If I fix the composition of the phase I, then the temperature and the composition of phase II will get fixed. That is the meaning of it. I shall show you all these with a system. Okay. Then if I have three phases present in the system, variables I have…..?

Student: 4.

Professor: 4. Composition of phase I, II and III, three variables, temperature the fourth and I have 0 degrees of freedom. All the four will be fixed. Composition of phase I, II, III and the temperature, everything will be fixed, such a thing is like a triple point in the unary system. We call such situations invariant. No variables can be varies. Okay.

“Professor-student conversation ends.”

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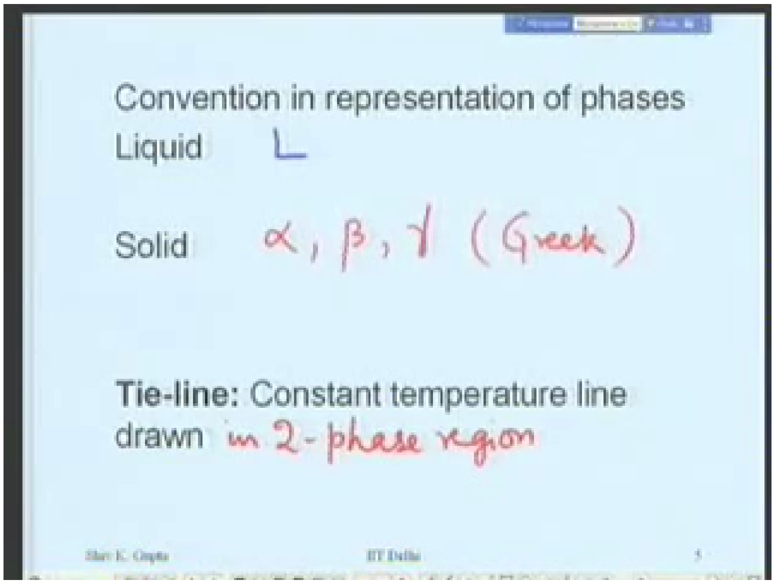

Convention in representation of phases

Liquid L

Solid α, β, γ (Greek)

Tie-line: Constant temperature line drawn in 2-phase region

Now before I start making the diagram, we use the convention for writing liquids, we use L. For writing solids, we use alpha, beta, gamma, Greek alphabets is what we use. And we are not looking at the system where they have gases present there. So looking at liquids and solids. The solid melts, I get liquid. Then I define another thing in the diagram, a tie-line. A tie-line is drawn, in the diagram now I have what are the variables? Composition and temperature. Composition axis is one which is finite, temperature axis is semi-infinite.

And we draw a constant temperature line in 2-phase region, that is important. This is not drawn in single phase region. In that case once we do that, the ends of the tie-line are ending at the ends of the 2-phase region.

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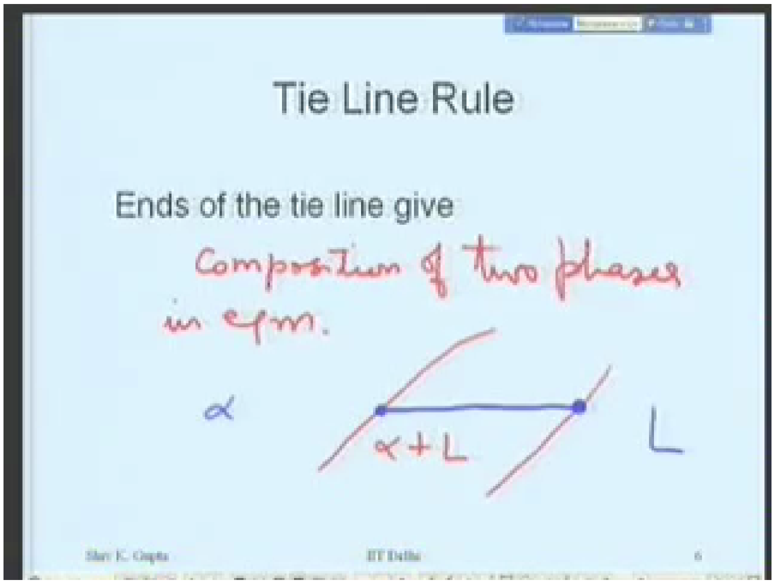

Tie Line Rule

Ends of the tie line give

Composition of two phases in eqm.

And they give, or this designs the composition of two phases which are in equilibrium. Let us say I have this two-phase region, alpha and liquid. In this two-phase region this is let us say is the contact temperature line. And let us say here is the alpha region, here is the liquid phase region. I am just saying that, okay. So this gives me the composition of the alpha phase, this gives me the composition of liquid phase. Is that clear? So we will look at the actual diagram, this is just hypothetical thing which I showed you.

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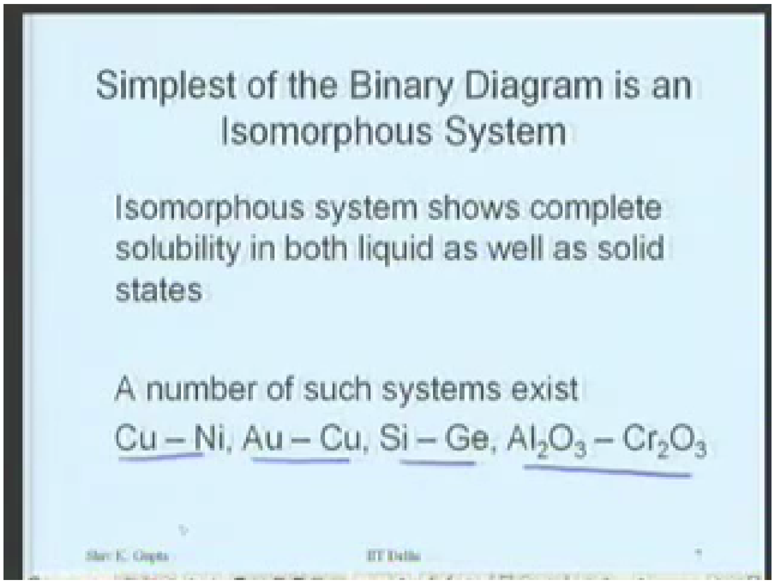

Simplest of the Binary Diagram is an Isomorphous System

Isomorphous system shows complete solubility in both liquid as well as solid states

A number of such systems exist

Cu – Ni, Au – Cu, Si – Ge, $Al_2O_3 – Cr_2O_3$

We shall now look at the one of the simplest of the binary diagrams, is called an isomorphous system. Isomorphous means the two components dissolved in all proportions in the solid state as well as they do so in the liquid state. We shall be seeing the diagrams where most of these components dissolve in all proportions in the liquid state but they may do so in solid state, they may not do so in solid state. If they do so, if they dissolve in each other in all proportions, I call it an isomorphous system.

Iso means same, morphous, morphology is the same. In the solid state, it is all the way FCC, it is FCC from 0 percent of B to 100 percent of B. If it is HCP from 0 percent of B to 100 percent B, it is HCP. That is morphology. And that is why it is called an isomorphous system. Some of the examples of the isomorphous systems are copper-nickel diagram is one, gold-copper diagram is another, silicon-germanium diagram, Al2O3-Cr2O3 diagram is another one. These are the ones which are providing the gemstones, okay. (())(18:34) comes from there.

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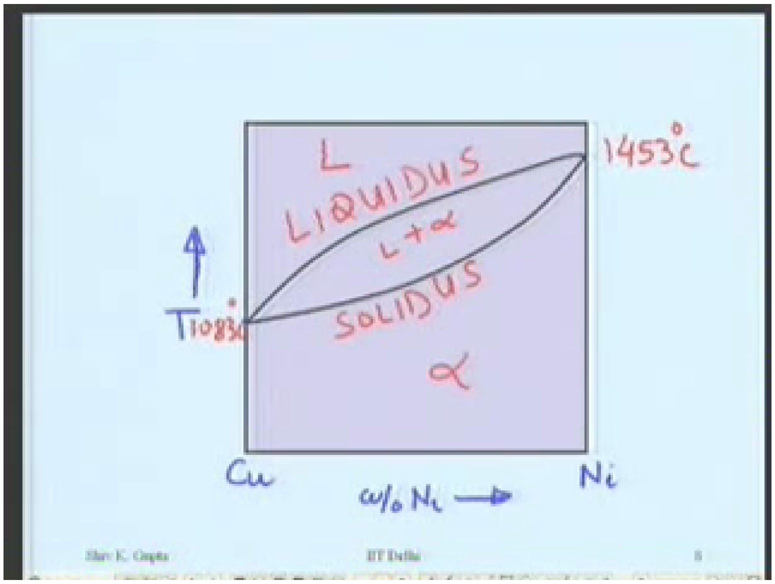

All right. Here I, let me show you a diagram, this is the composition axis, weight percent of let us say nickel, this is 100 percent nickel and this is 100 percent copper. That is the temperature and here is the melting point of copper which is 1,083 degree centigrade. This is the melting point of nickel, 1,453 degree centigrade.

And this is the single phase field liquid, this is the single phase field alpha. Solid phse we call alpha and in between I have the 2-phase region here. In this diagram, I have only two lines. One is the line, this one which I call liquidus. There is another line which is here, we call it solidus. And as I already said this is 0 percent nickel at this end, 100 percent nickel at that end. What is liquidus, what is solidus, let us define that.

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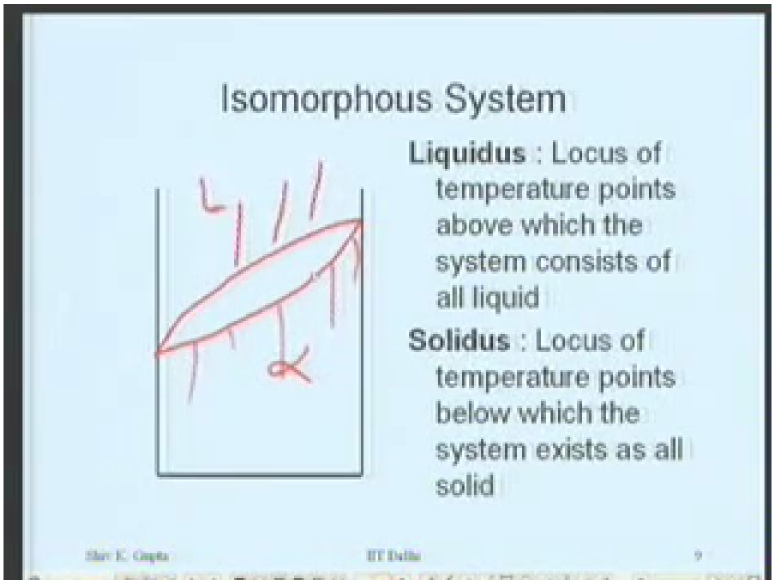

Isomorphous System

Liquidus : Locus of temperature points above which the system consists of all liquid

Solidus : Locus of temperature points below which the system exists as all solid

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Liquidus is the locus of temperature points above which the system exists only as liquid and I have not defined what exists below that. Above the temperature it is, above this temperature it all exists as liquid. What exists below this temperature I am not defining. Similarly solidus is defined as locus of temperature points, below that temperature it is always solid. What is above the temperature is still not defined. So below this line it is all solid, alpha phase field, that is the solidus. Between the liquidus and solidus, I have the 2-phase field which contains liquid and solid.

“Professor-student conversation starts.”

Student: Sir…..?

Professor: Yes, please.

Student: Inside the curve, we have (())(22:01).

Professor: Yes.

Student: So the degree of freedom inside is 2.

Professor: Yes, 1.

Student: Sir, inside the curve.

Professor: Please let me see how to read the diagram. Not told you how to read the diagram. I have to show you the three variables first, right? I have given you table, I have to show you the three variables, how to read that. Though I have already given the hint, I would explain that.

“Professor-student conversation ends.”

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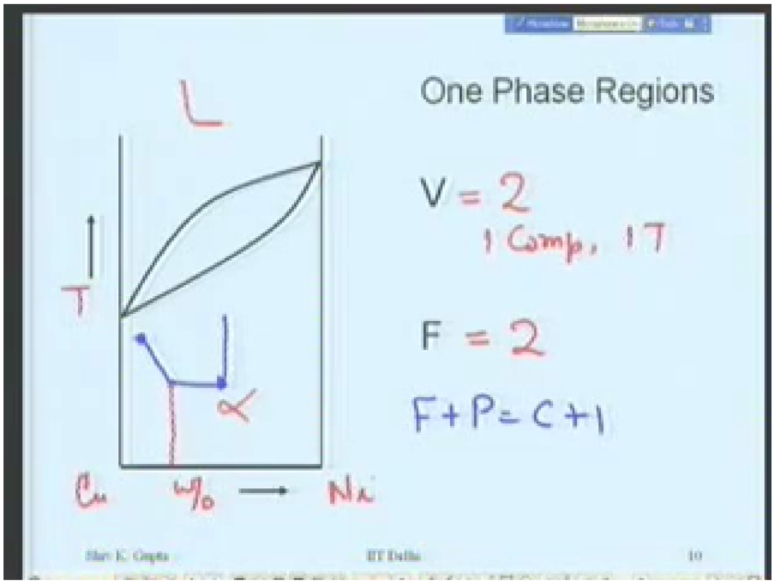

One Phase Regions

$V = 2$

1 Comp, 1T

$F = 2$

$F + P = C + 1$

Let us all first of all read the 1-phase region. In 1-phase region we have are two. One is the composition, another one is the temperature. P into C minus 1, 1 into 1, 2 minus 1 is 1, so that is only composition variable plus one temperature. Degrees of freedom, 2. Both the variables, composition and temperature within the boundary, so the system you can change. The boundaries are here, this solidus and this temperature line is composition line and that temperature, these are the boundaries.

Within this let us say I am at this position, at this composition. I change from here the composition to this value, still in alpha phase. I change the temperature also let us say, this while I am still in alpha region. Well, you can go from here both changing composition and temperature, still in alpha region. Both the variables are the degrees of freedom as long as you are within the bounds of the area. Same is true about the liquid region. All right. So that is how the phase rule is to be read here. Phase rule which is again write, all right.

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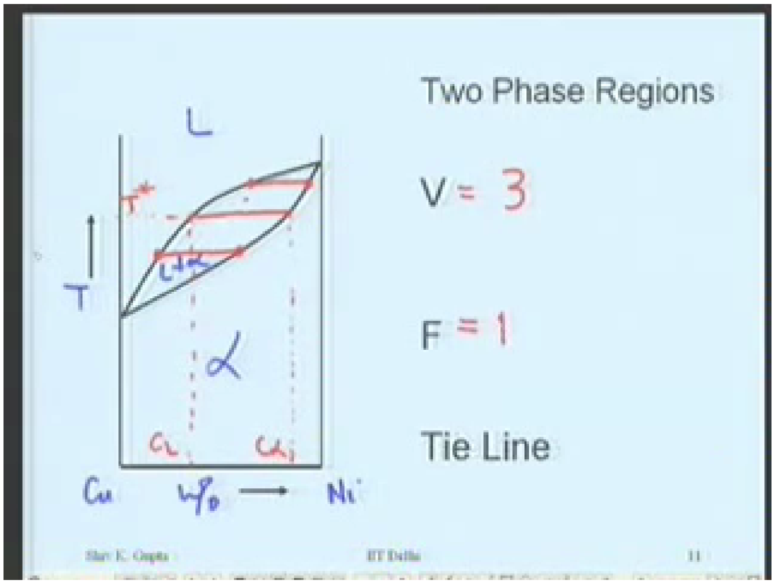

Two Phase Regions

V = 3

F = 1

Tie Line

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Let us look at the 2-phase region now. This is the 2-phase region here. To read the 2-phase region we draw a tie-line where, so the equilibrium is seen by the tie-line. This is liquidus and I have drawn the line down to the composition axis, that gives me the composition of the liquid phase. This is the liquidus, I draw the line parallel to the temperature axis on the composition axis, this give me the composition of the alpha phase.

And when I read on the temperature axis, I read this is the temperature. Let us call it T star. At temperature T star, in this region the two phases which are in equilibrium have the composition, see liquid for the liquid composition phase, see alpha for the solid phase. They are in equilibrium. These are how you read the three variables. So in 2-phase region the variables I have are 3 and degrees of freedom I have is 1. That you can go back to your table to see that.

Out of the three variables, the temperature T star, composition of the liquid phase CL, composition of the alpha phase C alpha, you fix anyone. Which one should be fixed? Let us say T star, temperature. At that temperature, this is the only tie-line in this region and this is the end of the tie-line on the liquidus. This is the composition of liquid phase here L. this is the end of the tie-line on the solidus, that gives me the composition of the alpha phase, solid phase.

So CL and C alpha get fixed automatically once I fix the temperature. Let us say you decide to fix, you want to find out what is the composition of the liquid and what is the temperature at which solid of C alpha composition is in equilibrium. So find out C alpha, draw a line parallel to temperature axis up to the solidus. From there draw a tie-line, that gives you the temperature at which this is in equilibrium and the end of the tie-line on the liquidus, gives the composition of the liquid phase which is equilibrium. That is how this phase rule is looked at in this diagram. And phase rule says there is only one degree of freedom.

“Professor-student conversation starts.”

Student: Sir, liquid to alpha region we can change the composition and temperature simultaneously?

Professor: I can change the composition and temperature simultaneously, yes, of what?

Student: Alpha region.

Professor: But the composition of what I am changing? This question is this. Composition of the alpha phase I can change along the solidus only. Composition of the liquid phase I can change along the liquidus. I cannot change the composition from this to this like that for the liquid. No, I do not have liquid here. Do I have liquid there? Liquid is only above this liquidus.

Student: Sir, what I am saying is within liquidus-alpha region we can change for the particular point within the region, within the area.

Professor: Changing of what? I have two phases. I am changing composition of what? One phase or both the phases? What is that you are asking? Now when you have two phases, you have to worry about the composition of the each one of them. Composition of one varies in this region along this line, that is for the liquid. Composition of the solid varies along this line and when two of them have to be in equilibrium. Okay. Two of them are in equilibrium at a constant temperature only.

This one is in equilibrium with that at this temperature. Similarly yet another temperature also they can be in equilibrium. I have changed the temperature but what is in equilibrium is this composition of the alpha phase and that composition of the liquid phase which are different from these. It is not the same equilibrium, it is a different equilibrium. At some other temperature, let us say lower temperature here, this is the solid which is in equilibrium with this liquid and the temperature is different.

Student: Sir, between that two phases are in equilibrium with specific concentration in both the…...

Professor: Obviously because I have only one degree of freedom. I am looking at particular temperature, then the two phases, I have the two compositions which are fixed. Composition of liquid phase as that of the solid phase, they are all fixed. I cannot change at this temperature.

Student: At equilibrium.

Professor: At equilibrium. Otherwise they are not in equilibrium. If…..

Student: This is the area between them.

Professor: Yeah, they are in equilibrium. Is this clear? In this diagram I do not have three phases in equilibrium. When I have an isomorphous system, in the isomorphous system I do not have three phases coexisting together. Three phases can coexist together in systems which do not so complete solubility in the solid state. We shall come and talk about that when we reach there.

“Professor-student conversation ends.”

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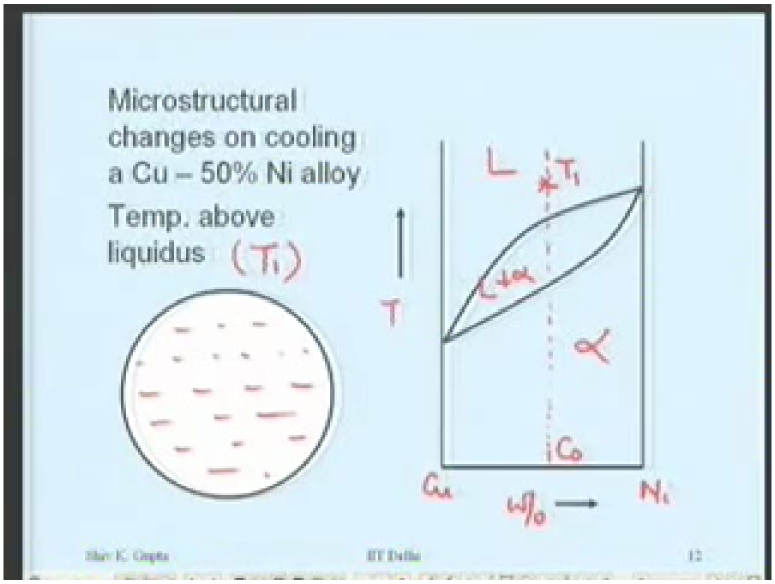

Microstructural changes on cooling a Cu – 50% Ni alloy

Temp. above liquidus (T₁)

Now before I proceed further, I take let us say in this system an alloy which I made by adding 50 grams of copper and 50 grams of nickel. So composition if 50-50. I call this composition C0. I take 50 grams of copper, 50 grams of nickel, put them in crucible, take it in furnace say up to about 49 degree centigrade and melt it. Sit it completely, make a good melt, homogenous melt. Right. Now it is asking what shall be the microstructure of this alloy when it is cooled at different temperatures from the melting point.

Let us say I am at this temperature which is in the molten state, liquid state, call this temperature T1. It is above liquidus. It shall be all liquid, there will be nothing else. In the crucible I shall see all liquid because I am in a phase field where there is only single phase which is liquid. This situation shall remain till I reach the temperature of liquidus. When I come below liquidus, solid will begin to come in equilibrium with it. That shall, solid will start to form. In other words, for this alloy solidification begins below liquidus and that solidification shall continue up to solidus. Let us look at what happens in this temperature range.

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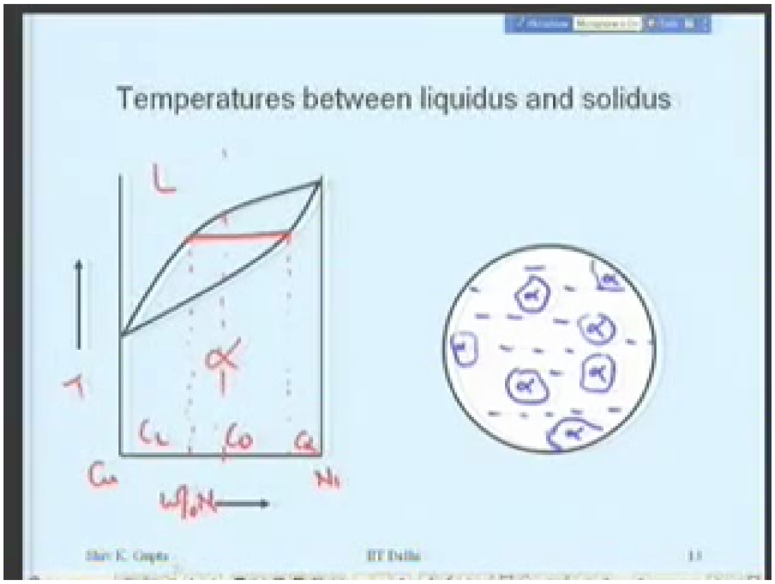

Temperatures between liquidus and solidus

The temperature between liquidus and solidus, let us say some temperature here. This is the composition of the liquid phase which is different from C0. And this is the composition of the solid phase which is also different from C0. C0, CL and C alpha, these are in equilibrium. So I have a liquid in which some particles of alpha phase are there.

“Professor-student conversation starts.”

Student: With composition CL.

Professor: With composition CL but these are the alpha phase particles.

Student: This is unique. For this temperature this C alpha in the region will be.

Professor: Yeah. This is, equilibrium composition is that only and rest is all liquid. That is how the microstructure will look like, my system would like. Look in the crucible, this is how it would look like. Some particles are solid floating with the composition here and the liquid with the composition there. And this situation shall go on till I cool, cool, cool, reach up to the solidus. But the amount of solid will keep on increasing. Amount of solid was 0 just at the liquidus and this amount of solid shall keep on increasing as I go down, down, down and it shall become all solid by the time I reach solidus.

“Professor-student conversation ends.”

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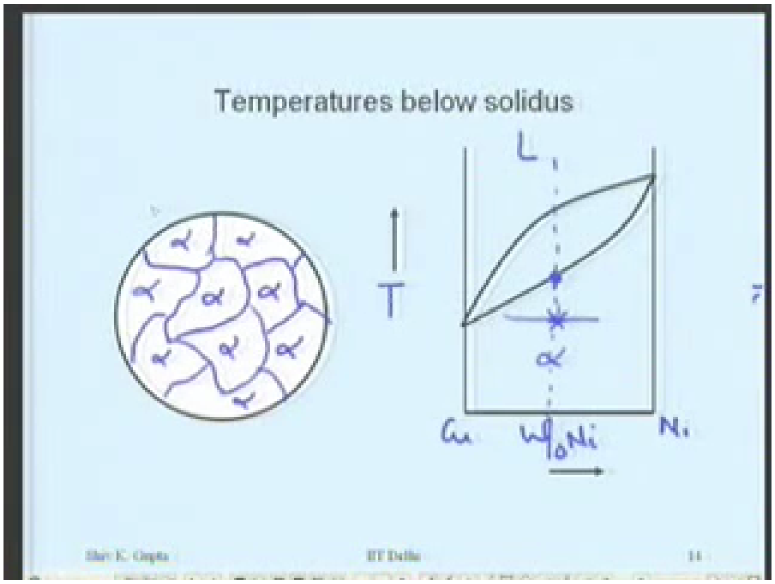

Temperatures below solidus

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So now below solidus. Once I reach here below any other temperature, let us say at this temperature, this will be all solid. Now all the particles which are formed, they start impinging on each other after a while and I form a polycrystalline solid like this. Usually we get polycrystalline solid. Each one is a grain of alpha phase and you have the grain boundaries in between. That is what happens now below solidus.

“Professor-student conversation starts.”

Student: Solidus where it intersects solid.

Professor: Yes, this will be, this has all become already 100 percent solid. Now below this it shall all remain 100 percent solid because that is the definition of solidus. At temperatures below this, it is all 100 percent solid but it is polycrystalline, it is not a single crystal. Usually the way we grow it or we solidify it, automatically it will form a polycrystalline one because in nucleation liquidus begins at more than, more number of places than one and then they each grow in size and some more nucleate as we cool. And that is how the amount of solid keeps on increasing.

So in this alloy the solidification is not taking place at single temperature, it is not congruent melting. Like that the pure copper melts at 1,083, pure nickel melts at 1,453 and this is the congruent melting. At a single temperature it melts. But in here it melts over, solidifies over a range of temperature starting from liquidus up to the solidus. Okay. So you see you have an alloy of composition C0 but in a 2-phase region I have two separate phases, each one of different composition.

But the total composition of the alloy combining alpha and beta together, liquid and alpha together is only C0. Mass has to be balanced, mass cannot be, it cannot remain unbalanced. Whatever you started with, you started with 50 grams of copper, 50 grams of nickel, that is getting divided into two phases, liquid and alpha but different composition, in different proportions. And that goes on during solidification.

Student: So those compositions remain same?

Professor: Composition of the overall alloy which is the combination of alpha and liquid together. That shall remain the same.

Student: Even if all the liquid as it relate to alpha, in that alpha…..

Professor: All the liquid is 50 gram of nickel, 50, all the solid, 50 gram of nickel, 50 gram of copper. But alpha and beta when two are existing together, may not be 50-50. One will have less of copper, other will have more of copper. Is that clear? Right, that is what I will show here now.

“Professor-student conversation ends.”

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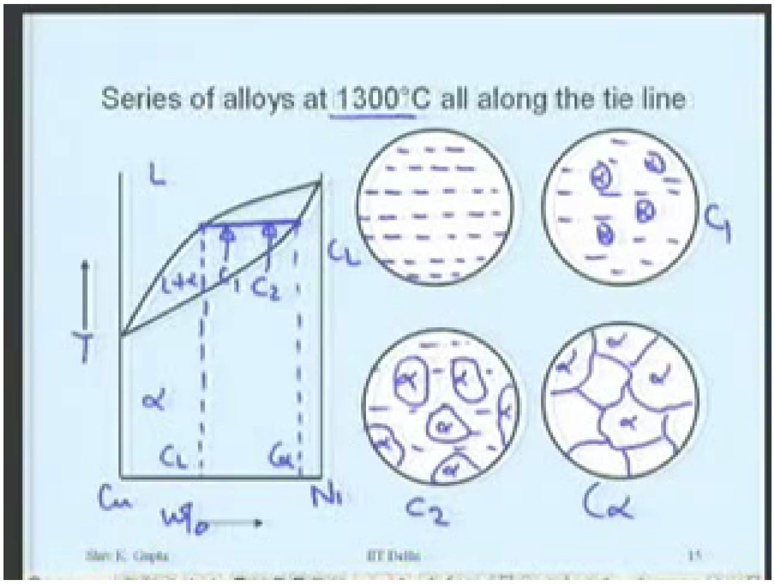

Series of alloys at 1300°C all along the tie line

Series of alloys at a constant temperature, let us say 1,300 degree centigrade. Let us say this is 1,300 degree centigrade. This is liquid here, alpha here, liquid plus alpha there. That is the composition of the liquid phase and that is the composition of the solid phase. Let us take one alloy which has a composition CL at this temperature. Alloy which has a composition CL, what shall it have? What shall it will show me?

“Professor-student conversation starts.”

Professor: The composition of the alloy itself is CL. At this temperature what will it show? All liquid, 100 percent liquid it will show.

Student: If you have this temperature, the alpha will, can also exist in equilibrium. Can alpha exist?

Professor: I will come to that. I am just at the liquidus. What should be the amount of the solid? We will come to that. So this is going to be all liquid. Well, if I have a composition of the alloy, C1, it shall have liquid and solid both. The liquid of this composition and solid state of that composition. Amount of solid would be small probably, not very large. Alpha phase is present here and rest is all liquid. That is composition C1, that is composition CL.

Let us take another composition here, C2, slightly still to the right but less than CL, alpha. It will have more solid probably than what we had in the earlier case. And you shall have less liquid.

This is composition C2. But fourth composition let us take is composition C alpha. It is all solid and all alpha grains. So I had 100 percent liquid, here I have 100 percent solid. In between the amount of the two phases is varying but the composition of the two phases is the same.

Liquid composition is CL. Here the liquid composition CL, alpha composition C alpha. Liquid composition CL, alpha composition C alpha, alpha composition is C alpha. Compositions are not varying as long as the temperature has been maintained at 1,300 degree centigrade. Temperature is constant, fixed. Is that clear? Right.

Student: Sir, in C1 whatever amount of C alpha, solid has appeared, it has appeared with the composition…..

Professor: C alpha only, yes. That is the equilibrium means that. I am talking about the equilibrium diagram. If it is not in equilibrium, non-equilibrium could be anything. But if it is in equilibrium, that is what it is.

“Professor-student conversation ends.”

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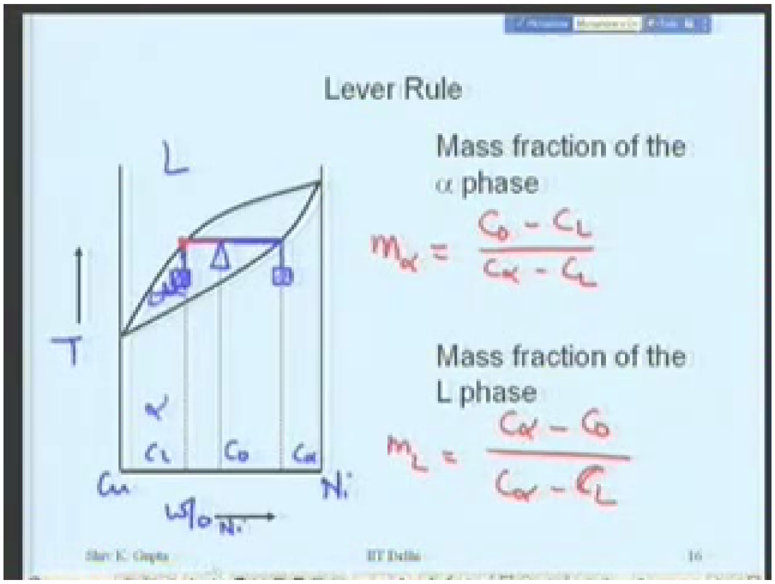

Lever Rule

Mass fraction of the α phase

$$m_\alpha = \frac{C_0 - C_L}{C_\alpha - C_L}$$

Mass fraction of the L phase

$$m_L = \frac{C_\alpha - C_0}{C_\alpha - C_L}$$

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Now I have introduced already saying that at this alloy, that is 2-phase region here. This temperature is tie-line. Let us say I take an alloy composition C0. The composition of the liquid is CL and composition of the solid is C alpha. At this temperature, this is my C0 alloy. I consider to find out the relative amounts. I showed you just now how the composition of the alloy changes the amount of solid it is changing.

But I am going to give you now what are the relative proportion of the two phases. It can be given, it is of course nothing but the mass balance. I suggest there is a problem in the book as well as I suggest that you work it out. Balance the mass in liquid phase and the alpha phase and put it equal to the total mass which is there in the alloy. We will see that. The tie-line acts as a lever of the first kind. With the overall composition of the alloy as a fulcrum, mass of the liquid phase hanging at the liquidus and mass of the solid phase hanging at this end of the solidus and tie-line has to be maintained horizontal.

So the mass of the solid phase which hangs here and the mass of the liquid phase which hangs here, they have to be in proportion to the arm of the lever which is opposite. For the liquid it should be this, and for the solid it should be that so that the lever is maintained horizontal. You can say the mass fraction of the alpha phase, I call it m alpha is equal to, proportion of the alpha phase is here, so it is opposite arm of the lever is this. So that is C0 minus C liquid divided by C alpha minus C liquid.

This arm of the lever divided by the total arm of the lever or total length of the lever, that is the denominator. Similarly the mass fraction of the liquid phase is proportional to this opposite arm, will be C alpha minus C0 divided by C alpha minus C liquid. That is what we call the lever rule and this can always be worked out.

“Professor-student conversation starts.”

Professor: Now I shall answer your question, what is the amount of solid when I am at the liquidus here? My fulcrum is right at the CL, what shall be the amount of solid?

Student: 0.

Professor: 0. So I showed you complete liquid there. Amount of the liquid is 0, solid is 0 here and amount of the liquid of the same count will be 0 there. That is why I say it is solid phase hanging here, is the liquid phase hanging there. Is that clear? Right.

“Professor-student conversation ends.”

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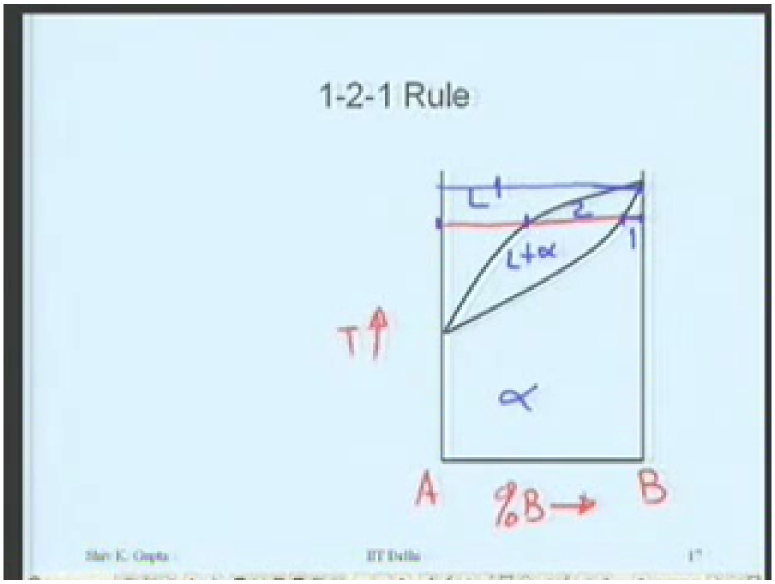
1-2-1 Rule

Now there is, I have told you about the phase rule. I told you about the tie-line and tie-line rule. I told you about the lever rule. We will tell you about another rule what is called 1-2-1 rule. 1-2-1 rule, in the phase diagram you draw any constant temperature line. Let us say this is A, B, percentage of B there, temperature here. Draw a constant temperature line here. Along this line I have phases arranged, 1-2-1-2, like that, as 1-2-1-2. That means every 2-phase region on either side has a single phase region.

And those two single phases are those which are present in that 2-phase region. That is if you look at here, from this temperature axis up to this liquidus, I have liquid phase present here, that is 1. Between this liquidus and this solidus, I have two phases present, liquid and solid. And from this solidus up to this temperature axis, I have only one phase present. That is 1-2-1. Now 1-phase region can be very narrow, it can be very wide.

See, it can be narrow. It can be so narrow that in this axis which I am showing it may just look like one single line. Plus, it can be little wider which you can show with a diagram. Depends what percentage range you are talking about, here I show the 1-phase region is this much as compared to that. If I was at a still high temperature here, what is the 1-phase region? Very narrow. So that is why I said 1- phase can be narrow, it can be as narrow that I can show it just as a point or a line in the diagram because after all 0 percent to 100 percent has to come within this range A to B. 0 percent to 100 percent it has to come. Okay. So that is what is 1-2-1 rule.

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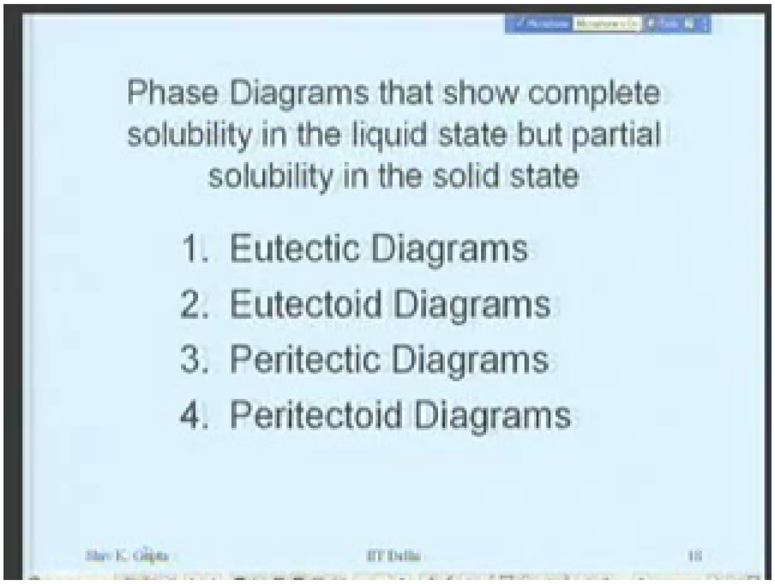

Phase Diagrams that show complete solubility in the liquid state but partial solubility in the solid state

1. Eutectic Diagrams
2. Eutectoid Diagrams
3. Peritectic Diagrams
4. Peritectoid Diagrams

All right. Next we try to look at the other kind of diagrams which show partial solubility in the solid state while they show complete solubility in the liquid state. Some of these diagrams I mentioned, I am not mentioning all such diagrams: Eutectic diagram, eutectoid diagrams, peritectic diagram and peritectoid diagrams. We shall see them one by one. We shall first start with the eutectic diagram.

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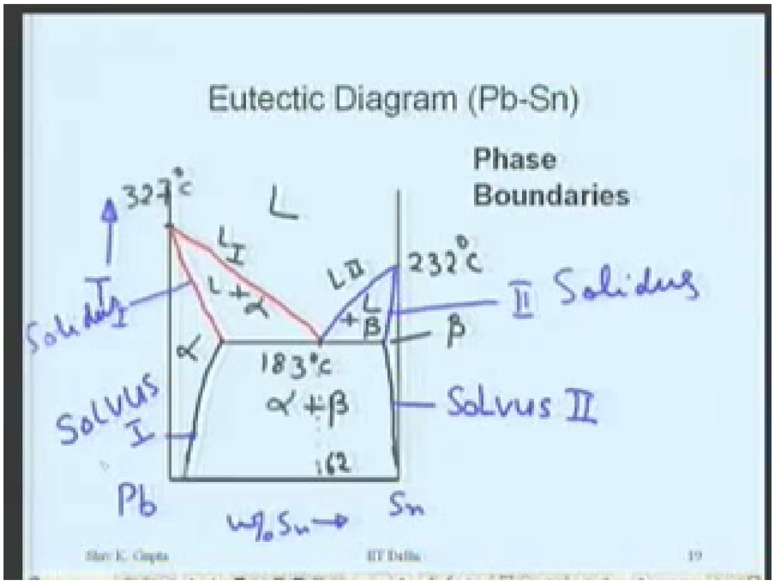

Eutectic Diagram (Pb-Sn)

Let us say Pb here, weigh percent tin there and here is the temperature axis. The melting point of lead, liquid phase field, alpha phase field, that is the beta phase field. Here I have liquid and alpha phase field, liquid and beta phase field, alpha and beta phase field. Here we have boundaries which are defined liquidus, this is liquidus one, from the melting point of lead which is 327 degree centigrade goes up to this temperature which is 183 degree centigrade. And this composition up to which it goes, is 62 percent of tin.

And the second liquidus here. It starts at the melting point of tin which is 232 degree centigrade and goes again to 183 at 62 percent. Similarly I have this solidus line here, this is one solidus line and that is the second solidus line here. Besides that I have this boundary and I have this boundary, plus I have this line. These are the additional things other than the liquidus and solidus which I defined earlier.

Solidus below which it is all solid, liquidus above which it is all liquid but what is this line? This is the solubility limit. It gives how much tin can be dissolved in lead at a given temperature and then it becomes supersaturated. So solubility of tin in lead is given by this line at different temperature, is called the solvus and you can call it solvus I. Similarly this one can be called solvus II. That is how much lead can go in tin, the solubility limit of lead in tin. All right, that is called the solvus line. Well, in complex diagrams we shall see more of this and this temperature line, constant temperature line, 103 degree centigrade, we shall see in the next class.