Phase Diagrams in Materials Science Engineering
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Lecture - 08
Binary Isomorphous System

In the last class, I briefly explained you how to get two-dimensional binary phase diagrams at a constant pressure one atmospheric.

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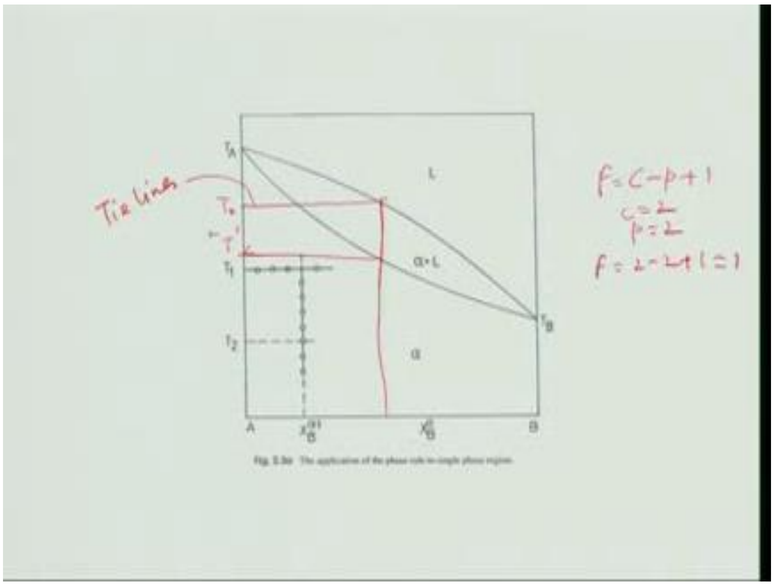

Then I discussed with you how to apply phase rule; in the both the single co regions liquid and alpha where alpha is a solid phase and L transform the liquid. Now, let us do this again once more, so that you do not forget. So, let us consider first a composition Xs; composition X B alpha and I just can have different temperatures that in each dot correspond to one temperature you can see. And L will be remaining between the alpha phase (Refer Time: 01:07) so that means, if I select composition first and then I have many temperatures still I remain the alpha phase I do not change.

Similarly, if I take a temperature different temperature one temperature suppose T 1, I can have many composition so the alpha is stable that means within the alpha phase I can varied both temperature composition alternatively all together you can have temperature T 1, T 2 composition this, this, this, so many compositions still you will be in alpha phase field. So, you have two basically you have two independent variables two variables are there that can be changed simultaneously; keeping in mind that alpha phase field remain alpha phase filed, we do not change.

So, let us do that for the two phase region as you know F degree of freedom is given as C minus P plus 1. C is the component, P is the number of phase and one correspond to temperature so how many component say two because it is a binary phase diagram. So, in a two phase region or isomorphous liquid, we have two phases P is equal to two; F is equal to 2 minus 2 plus 1 that is equal to 1 so that means, I have only one degrees of freedom. In the liquid or in the alpha phase will have two degrees of freedom, but within the two phase (Refer Time: 02:33) region, I have only one degrees of freedom.

What is the meaning of that? Let us first consider temperature. Suppose, I choose I have the why I have to choose the temperature. So, I choose the temperature like this. If I choose the temperature; that means, I draw a horizontal line with respect to the x-axis. And these lines actually are known as tie lines please remember this all though I will be taking telling many things, but you should remember these are called tie lines; that means, tie lines are lines which are joined parallel to the x-axis parallel to the compositional axis passing through the two phase region. Why that equal to tie line T i e means tie means tying a knot right. In a tie, we use tie, tie is nothing but something to wear or put a knot on tie; that means, you tie with it is something.

So, it ties the liquidus and solidus as you seen here. I drawn the two points here to this, this a liquidus and solidus curves intersected by this line so that mean this line ties two curves liquidus and solidus. Now, let us get back so if I choose a temperature as any temperature let us suppose a temperature is T naught and draw a horizontal line. (Refer Time: 03:57) my compositions are of the solid is given by this point; composition of liquid is given by this point. This is also very important you must remember. So, wherever the tie line intersects the solidus and liquidus and if I draw non particle non mark to the compositional axis, I will come to know the composition of solid and liquid phases. So, that means if I choose temperature (Refer Time: 04:26) compositions of solid and liquid phases are fixed I cannot change.

Suppose, if I check now I if I change take a composition like this, this is my independent (Refer Time: 04:43) I choose, I have power to choose composition I choose. So, now, if I choose the composition of liquidus, composition of this alloy then immediately temperatures are fixed why because this composition will melt at temperature T naught very easily. it will start melting at this temperature. Suppose t dash and it is ends melting at T naught because that is the liquidus this is solidus. (Refer Time: 05:10) solidus everything is solidus I have liquidus everything in this liquid.

So, in between only the solid and liquid region is present so that means, if I choose composition or temperature one of these two other variable is fixed I cannot do anything I cannot change, thus so why I have one degrees of freedom. I can only choose temperature or composition. So, I hope you understood how to apply phase rule in a binary phase diagram. In a single component phase diagram (Refer Time: 05:38) phase rule is very simple. I have shown you for water, but in a binary system it is not so simple. You have to apply logic to do that.

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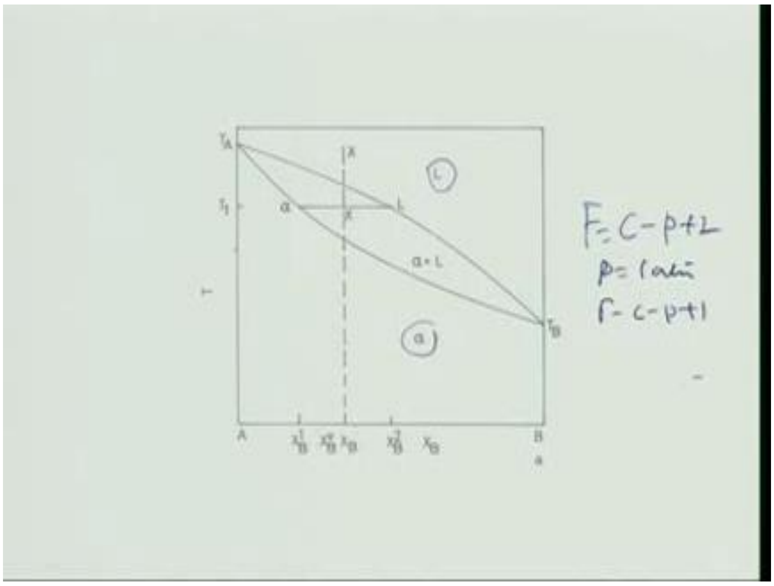

So, let us now talk little bit about tie lines more. So, let us discus about this one more; I go back to one slide and discus. So, as you see here I have both solid and liquid in the region and when I have two phase region bounded by these two solidus and liquidus curves which I have told you. Obviously, if I am an engineer, I must know how to measure what is the amount of alpha what is the amount of liquid present for any particular alloy composition, because it is a two phase there are two phases are present liquid plus alpha. So, I must be having an idea what is the percentage of the two phases consisting of alpha and how much percentage is due to liquid. Let us do that for a particular alloy composition. And from there actually we will come to know how to do how to apply lever rule, the very important concept because I have done phase rule now I will do values also.

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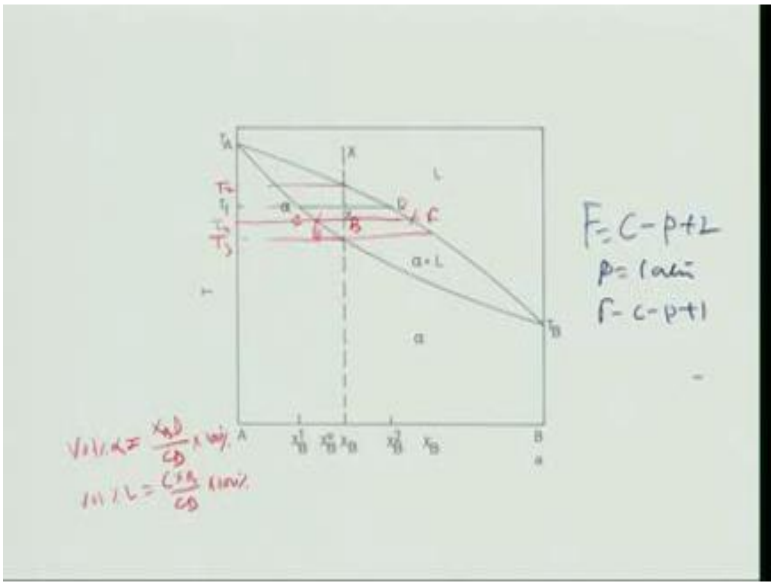

A lever rule is very important for binary quaternary alloys. This rule allows you to calculate the amount of phases present in terms of volume percentage or in terms of other percentage we can actually we can do that. Now, how to do that? Let us take an alloy composition X B. This is be given by these dotted line, and so these vertical line is passing through, now let us represent the temperature T 1, there are many temperatures see you can have many temperatures between these two where solid and liquid co exist. Above this temperature, suppose T 2, everything is liquid; below this temperature T 3, everything is solid.

So, only between T 2 and T 3, it is solid plus liquid, alpha plus liquid. So, I have chosen one temperature T 1 which lies between T 2 and T 3; and draw a tie line. Tie line knows what I told you tie line connects alpha a liquid; tie line connects solidus and liquidus that is what I marked alpha solidus liquidus L by this two points. So, now, if I see this tie line which intercepts the solidus at point A, at point not A let us use some other symbol, let us suppose I used a symbol C, capital C and this is at point D forget about that L. So, C and D is my line which is which are these C and D are the two points where this line intersect solidus and liquidus, and between the I have marked a point X why because the X is the alloy composition that is X B is the alloy composition. So, therefore, this is X B.

So, now, lever rule says very simply the volume percentage of alpha will be given by this on X B divide by the total lever C D, or let it put it in this way. We can always use C D as a lever and X B is the fulcrum of the lever. All of you have to use this hand pumps; so an hand pumps we use a lever to push the lever to get water out, so there also the lever as the fulcrum. Similarly, same thing same way let us assume C D is a lever - l e v e r, which X B is the at fulcrum X B which this point is at the fulcrum. Then volume fraction of alpha is given by a X D divided by C D. So, volume percentage of alpha is given by X B D divide by C D into 100, because it is a percentage that is why.

So that means, if you are sitting if alpha is lying on your left, the volume percentage measurements you have to consider the arm on the right of the fulcrum not on the left. But for the liquid it is obviously, same way it is equal to X B C or C X B divided by C D into 100 percentages. Why it is so because of liquid is on the right side or myself for me it is on the right side, so I take arm on the left side, because C X B is on the left side.

So, if you have; that means, you take the opposite term, if you are sitting if you phases on the right side you will take the arm of the left side of the fulcrum. If you phase on the left side, you take the arm on the right side of the fulcrum. And this is known as lever rule. This is can be easily determined by mass balance very simple. And one can actually do different kinds of calculations using this rule. So, I will not going to details of the derivation, but this is nothing but a mass balance nothing but a mass balance concept; it is not named by anybody else it is known by the lever itself.

So, as you see C and D is the lever X B is the fulcrum then we can do all calculations as I do. So, we can have any other temperatures suppose I have a temperature T 4 where I know the cutting points it is cutting points are E F suppose and X B is my fulcrum. So, you can see here that volume pressure of solid in alpha will be X B F divide by C E F here X B F divide by E F. Similarly, liquid is E X B divide by E F. So, one thing you can see that as you go down the temperature the volume pressure of solid is going to increase that is obvious more and more solid will solidify as you decrease the temperature. I hope this is clear to you.

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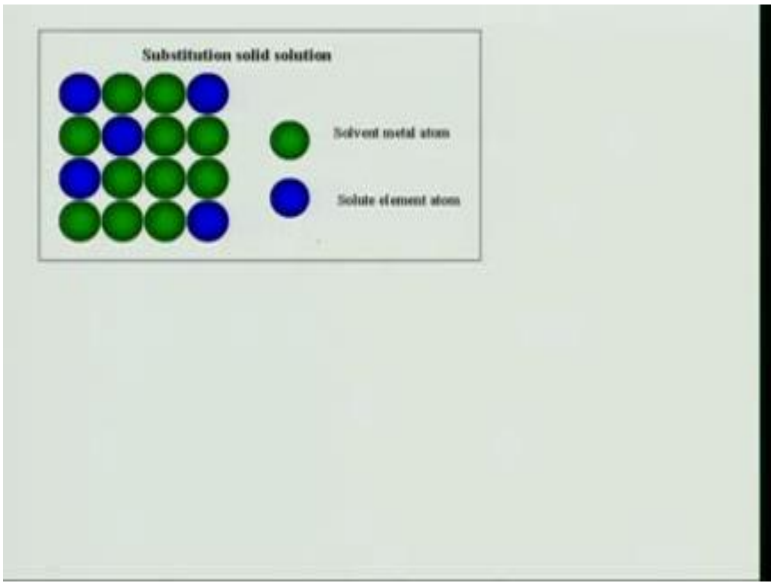

Now, so we can move to the next thing next step. So, before I do that let me just explain you that there are different types of solution exist like you know water with salt, water with sugar. If you take water with salt, it will be salty; similarly water with sugar it will be sweet, but what is atomistically solid solution means. Solid solution means the one I have shown you, suppose in a solid solution you have solvent and solid right, so water and suppose sugar water is solvent and sugar is solid. Similarly, solid solution is same concept, but it is in solid state instead of liquid because sugar all use to liquid so that is why we are we always say water and sugar, water and salt, but the concepts are exactly same. If you understand the liquid solution you can understand solid solution also. Atomistically what is it; it is suppose if I take your green atoms as a solvent now.

Initially suppose I have my solid is consisting only green atoms; that means, only one component. Now, if I add another component to it as a solid like if I add suppose these blue atom or blue symbol atom into it, what will do, it will this atom will go and it places solvent atom that is what is shown here. You can see here these are the solid atom which has occupied their place by replacing the solvent atoms; such a kind of solid solution is known as substitutional solid solutions. Substitutional means I have substitute it one atom of solvent with the solid that is why it is known as substitutional solid solutions. Iron with magnesium substitutional solid solution, aluminum with nickel is the substitutional solid solution.

You can clearly understand to have the substitutional solid solution you need atomic (Refer Time: 14:33) of stimulus. You cannot have a large difference of atoms actually then one atom cannot replace other because atoms it is in the lattice so it has specific size. So, if I want to replace an aluminum atom with a nickel, and the atomic sizes are vary value different, they will not be mix each other. So that means, there is something some rule actually I will talk about after sometime (Refer Time: 15:01) rule where how much is the size difference can be allowed to form such this isomorphous type of phase diagrams will be discussed.

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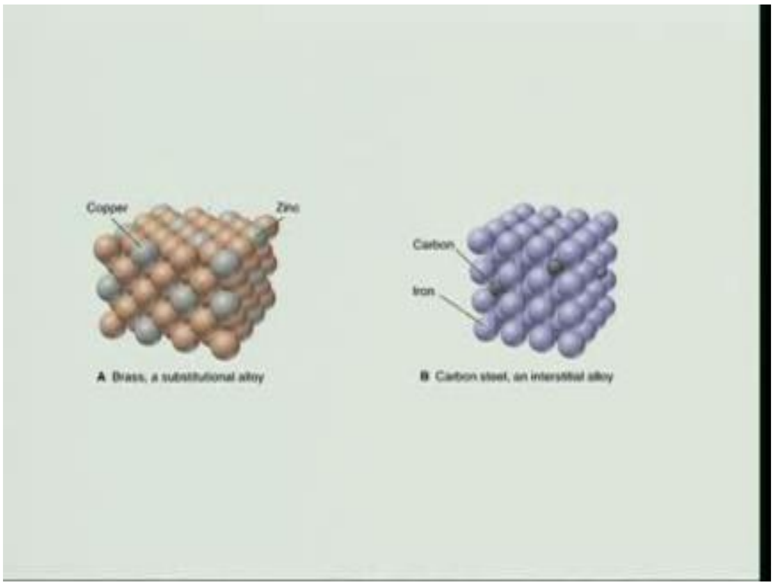

Now, there is another types of solid solutions which can happen, let me explain here. This copper zinc see here, this is a three-dimensional copper zinc substitutional solid solution is known as brass. Brass we all know brass is used in utensils (Refer Time: 15:27) also. So, you can see here the zinc atoms which are actually shown as grey, grey atoms are actually replacing the copper items in the fcc copper lattice that is all this is called substitutional solid solutions. Now, on the other hand we can also have what is known as interstitial solid solutions. What is that we know that if I go back one-step further, we know that these are voids in a lattice nothing is present in this between this points.

Now, if I have a small size atom and I allow their atom to occupy this small size to the space then I form what is known as substitutional solid solution, and that is what is shown in the three dimensional diagram this is the bcc iron alpha iron, and there are voids in that. You see carbon atoms are going to the voids. Our steel is like that steel is nothing but a substitution solid solution of carbon in iron. I had small amount of carbon about 0.3, 0.48 percentage. And these carbon atoms then go and sit in the interstitial positions. And as you know there are different types of interstitial, so one is tetrahedral, another is octahedral, these are basically voids.

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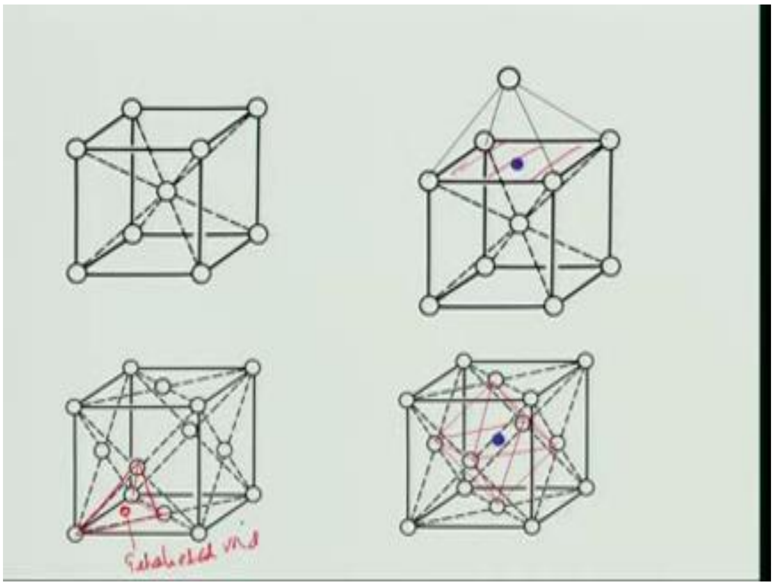

So, you can you can actually generate these three kind of voids let us assume iron only first. This is bcc iron, you can see the unit cell of bcc iron. There are central atom and eight corner atoms. So, you can clearly see if I have a two mixture I can generate a octahedral voids. Why it is called octahedral voids, because if I join these atoms I from the octahedron, octahedron is a eight face you can see here eight faces 1, 2, 3, 4, bottom one also eight faces, basically it as 4 plus 4 - 8 faces top four bottom four. So, at the center of that it does it void and. In fact, for bcc iron the voids it is on the top plain this plain on this plain. So, there are many, many such octahedral voids.

Similarly, there is a octahedral voids, similarly the tetrahedral voids how did you know tetrahedral voids very simple. If I can (Refer Time: 17:57) tetrahedral, octahedral voids may have many ways, but one of this is that as it has to be tetrahedron. So, in a fcc unit cell, it is very easy to show. So, this is the fcc unit cell. Suppose, gamma iron, you can clearly see I can actually have this tetrahedral like this it is a tetrahedral why this tetrahedral there is a four phases. So, at the center of this tetrahedron I can put voids, I can put an atom this is a void so this is known as tetrahedral void.

Similarly, in fcc unit cell at the center, this octahedral void sees I have drawn the octahedral, octahedral voids. So, a carbon atom actually goes into these voids. They sit there and that is why this is known as interstitial solid solution. Steel is known as interstitial solid solution. Whether carbon atom based voids of bcc or fcc does not matter, but because of solid inferences it has to go to voids; carbons are very small elements and this is why the steel is so strong. And you will come to much more as I go along why steel is strong because carbon atoms actually resist (Refer Time: 19:17) dislocations to these lattice that is why steel is very strong. And steel is one of (Refer Time: 19:22) material it has all properties, but it is a substitution it is interstitial solid solutions.

So, you understood that solid solutions can be of two types; one is known as substitution solid solution other one is interstitial solid solution. In substitution solid solutions, one atom replaces; the other atom solid atom replaces soluble atoms and forms the solid solutions. But in interstitial solid solutions solute atoms goes to the voids tetrahedral octahedral voids. This is also very important concept. If you do not understand this very careful now, there will be lot of problems in as I discuss other phase diagrams, so please be careful about it.

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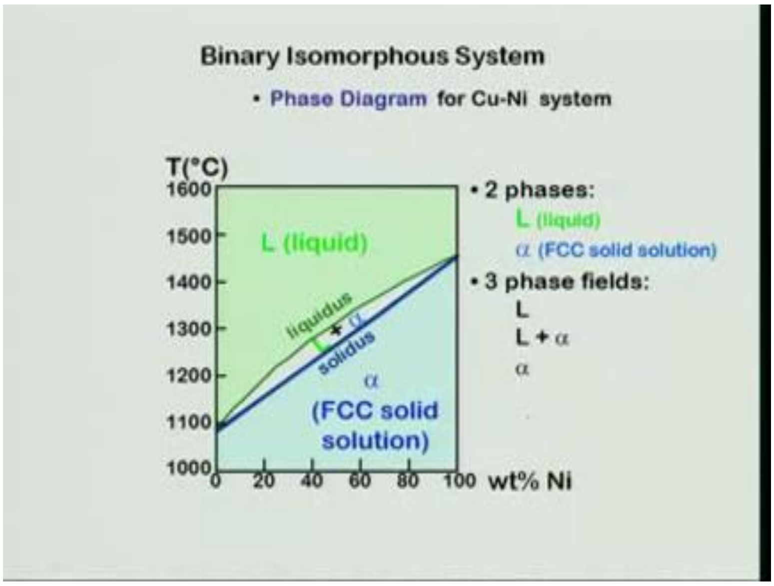

Now, so we have done all the backgrounds. Now whatever time I have in this class, I am going to discuss a very you know detail manner a phase diagrams which is known as copper and nickel. Copper and nickel, why copper and nickel to this copper and nickel both have (Refer Time: 20:31) structures; atoms values are similar. Copper has lattice parameter of 3.61 Armstrong, nickel has lattice parameter 3.58 Armstrong, so that what they are similar crystal structures, similar lattice parameter, similar atomic sizes they will form solid solutions.

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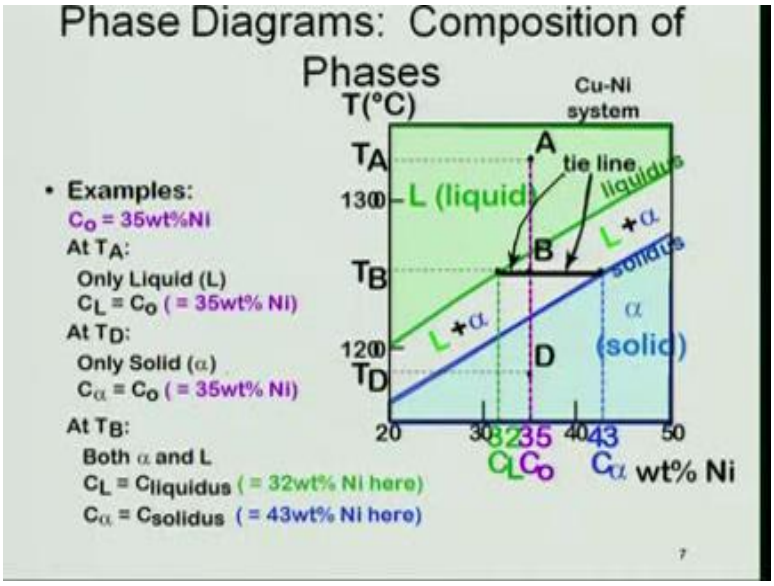

Now, again this phase diagram looks same as I told you the (Refer Time: 20:53) of a diagram liquid solid phases are separated by (Refer Time: 20:57) region which is solid and liquid. So, the upper or carbon is known as liquidus, the lower is known solidus. There are two phase regions liquid plus alpha; and three phase fields, three phase three there is no three phase layer and there is a basically two phases, two phases liquid and alpha. And three phase fields' liquid, alpha, liquid plus alpha. You see the (Refer Time: 21:30) to 8 percent of nickel 0 to 100 percent. Similarly, copper also copper melts at 1494 degree Celsius temperature, nickel melts at 14 53 degree Celsius temperature so that is all the phase diagram will look like.

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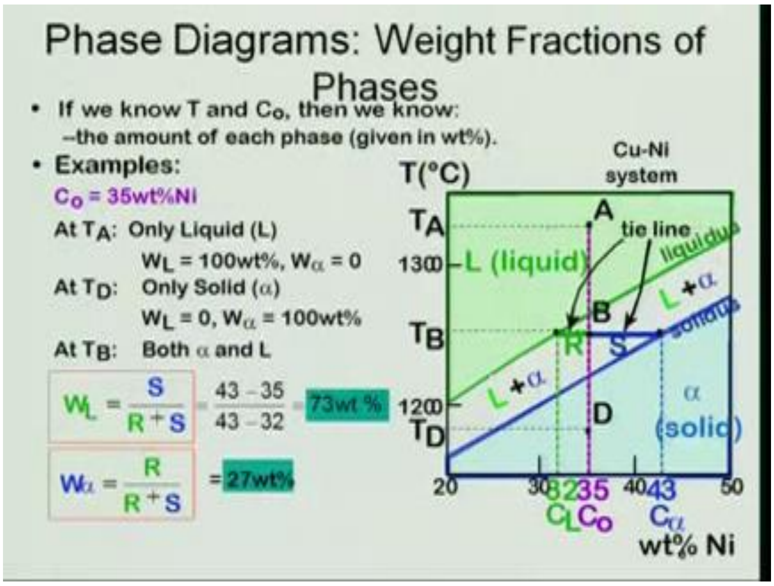

Now, if I apply lever rule, let us do that. I describe you suppose I will allow which is which contains 30 weight percent 35 weight percentage of a nickel. And I want to apply lever rule at a temperature T B, it is between 1200 and 1300, it is suppose a 1250 T B is equal to 1250. So, what I do I draw a horizontal line which is known as tie line which connects a liquidus and solidus, and if intersect liquidus and solidus at this points. So, I draw vertical lines from this points and get the solid composition is 32 percent nickel liquid composition is 43 percent nickel. So, as you see here a T B solid composition is 32 percent nickel, liquid composition is 43 percent nickel, sorry this is other way solid composition is 43 percent nickel, liquid composition is 32 percent nickel, because the top model is liquidus, bottom is solidus.

So, now how we are calculate that is what is done the vapors eight percentage of or eight percentage of liquid is given by S, S is this term, this is liquid (Refer Time: 23:09). So, I go to the opposite term this is this I am divide by R plus S. R is the distance between the composition and the liquid composition alloy liquid composition C is alloy composition and the solid composition. So, liquid percentage is the opposite term which is S divide by R plus S. And if you do that that is 43 minus 45 is this arm divide by 43 minus 32, so that is we usually 73 weight percentage.

Similarly, 8 percentage of the liquid is solid alpha is solid alpha is this side R divide by R plus S. We go to the opposite term R divide by R plus S so that is equal to R divide R is equal to 35 minus 32 is 3 divided by 43 minus 32 that is 9, 3 by 9 is nothing but 27 percentage. So, this is the way actual lever rule can be applied.

I will solve some other problems in later on until you have to do that.