Materials Science and Engineering
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Lecture – 14
Phase Diagram Part II

Hello friends. Let us start with the discussion on phase diagram to continue with what we left at the last lecture. Now coming to phase diagram, previously, we discussed about a phase; what do you mean by phase what do you mean by component, then we discussed about the Gibbs free energy and Gibbs phase rule ok. So, now, with all these concepts ok, now we will be able to give our attention to phase diagram where we will be able to use some of these ideas.

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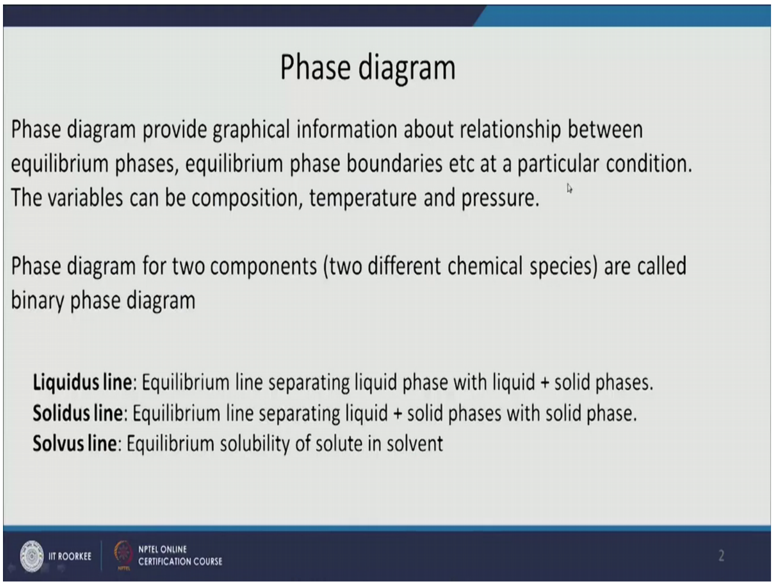

So, if you look at the slide phase diagram provide graphical information about relationship between equilibrium phases.

So, one thing you have to keep in mind that all the phase diagram which you see in the book or any other place, this all phase diagrams are equilibrium phase diagrams; that means, that all the phase transformations were done under equilibrium condition; that means, very slow equilibrium is when we want to have a equilibrium transformation ok; that means, we are able to always go back and the process is always a reversible process that is from thermodynamics that is what we understand ok. So, when I say equilibrium;

that means, I am doing this transformation very slowly and I am allowing all the diffusion of atoms to takes place suit so, that I can get a uniform composition in each phase throughout the throughout their volume ok.

As we; as you, if you remember when we discussed phase, we said it has to has homogenous composition. So, to achieve that you have to do all this transformation at very slow rate and that is why we call them as equilibrium phase diagram, but in reality whatever transformation, we do whatever processes we do they are at much faster rate ok. So, these are not can be called as equilibrium conditions these are non equilibrium conditions ok. So, though we understand all the phase transformation from the phase diagram ok, but in practice, we do not practice the same way as we have got the phase diagram.

So, phase diagram are equilibrium phase diagram, but in practice we do not follow the equilibrium conditions that you have to keep in mind. So, basically it gives you a graphical information about relationship between equilibrium phases; equilibrium phase boundary, etcetera at particular condition the variables can be composition temperature and pressure phase diagram for 2 components 2 different chemical species are called binary phase diagram ok. So, it can; there can be a unary phase diagram where you have only one component.

So, suppose if you want to draw a phase diagram for water, let us say, then it will be a unary phase diagram; that means, only one component or if you have 2 components which is which what we are going to discuss in more detail, those are called binary phase diagram, then there are ternary phase diagram and so on ok. So, we will going to discuss 2 component systems which are called binary phase diagrams then there are some terms which will come later on in the phase diagram one is liquidus line ok. So, it is equilibrium line separating liquid phase with liquid plus solid phase.

So, across this boundary the liquidus line ok, you have on one side, you have liquid phase on another side, you have liquid plus solid phases solidus line. Similarly, equilibrium line separating liquid plus solid phase with the solid phase ok. So, on one side, you will have liquid plus solid, another side, you have solid phase solvus line equilibrium solubility of solute in a solvent ok. So, one more line is there which gives you the equilibrium solubility of a particular solute in a solvent ok, as you remember, we said there will be a solid solution. So, solute can occupy a substitutional position or interstitial position ok.

So, there is a solubility limit for a given temperature and pressure above which I cannot add solute atom in the in a particular solvent, the solute will come out of the solvent, as if you take an example of again water and sugar up to some point, I can add keep on adding sugar, I can dissolve it in water, but after a certain point it will not be able to dissolve a more sugar, then its solubility limit ok. So, then I can keep on studying, but the sugar particles will remain like that I can add more or I can dissolve more sugar by increasing the temperature ok.

So; that means, I am altering the condition to increase the solubility that is possible, but for a given temperature up to a certain extent I can add a sugar in water, but after that it will not take it because it has reached the solubility limit you can change the solubility limit by changing some variable for example, one of them is temperature. So, if I increase the temperature I can dissolve more sugar now again you will later on reach this solubility limit again.

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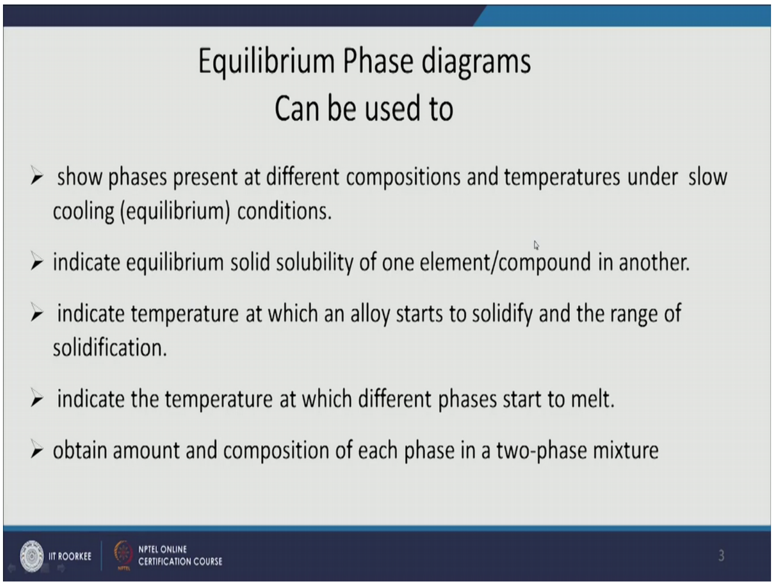

So, if you see equilibrium phase diagram on the slide, there are a lot of a applications are there and for what purposes I can use a equilibrium phase diagram.

So, it can be used to show phases present at different compositions and temperatures under slow cooling equilibrium conditions as I told you earlier also that equilibrium means I have to do it at a very slow rate. So, show; it shows phases present at different composition and temperatures at different composition and temperature what phases are going to be there phase diagram can tell me, it can be used to indicate equilibrium solid solubility of one element compound in another, as I just told you about water and sugar that it can give me that what is the equilibrium solute solubility of one element in another of solute in solvent.

It can be used to indicate temperature at which an alloy starts to solidify. Solidify and the range of solidification it can also give me at what temperature the solidification will start at what temperature the solidification will be completed ok. So, the all these temperature ranges will be given and the fixed temperature can be found out it can be used to indicate the temperature at which different phases start to melt; obviously, if I can get solidification I can also get the melting, it can be used to obtain amount and composition of each phase in 2 phase mixture or when you have 2 phases in equilibrium I can find out what is the amount of those 2 phases what is the composition of each of these phase ok.

So, I can get all this information. So, we go to the next slide and now we will start with a very simple binary phase diagram which is called isomorphous systems ok, the importance of this particular phase diagram or system is that in these systems both the components are completely soluble in each other ok. So, they have complete solubility in liquid and solid phases, for example, copper nickel system one of the system is copper nickel system ok.

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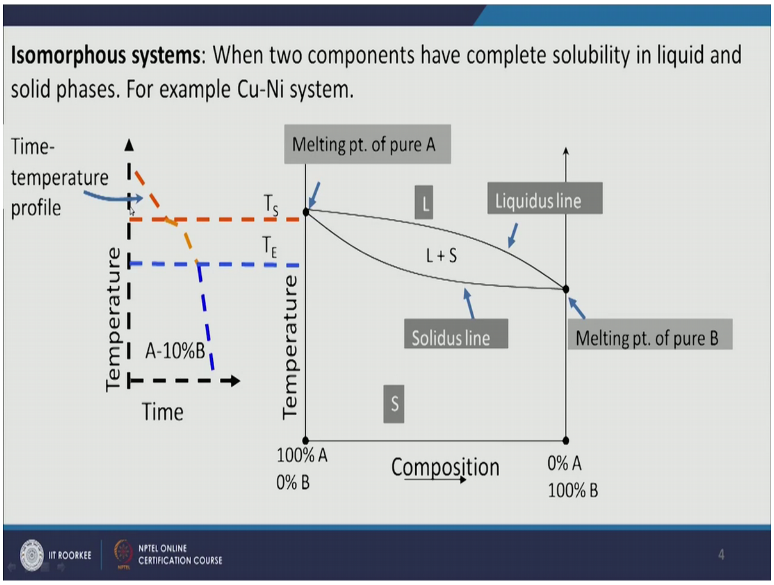

And the phase diagram is given here I can explain few things on the board one thing I want to bring out here if you remember in the previous lecture, we discussed about the time temperature curve ok.

And I told you at that time that you can use this time temperature curve to find out the phase diagram ok. So, for example, here one a time temperature curve is shown and this is for a particular composition. So, we made one composition, for example, here we have taken a 10 percent B alloy added into a. So, it is A 10 percent B alloy for which you have got this ok. So, this is the liquid phase and this is the phase transformation is started at this temperature the phase transformation is completed and the; then you have the temperature profile in the solid phase.

So, from one particular composition by measuring the temperature of the alloy as we are cooling down I can find out that at what temperature the phase transformation is started at what temperature the phase transformation is completed now that information I can use here. So, I can take a 10 percent alloy here and these 2 temperature if I plot it here it will give me 2 points for this phase boundaries and that is how you can find out for different composition and you start getting all the points if you join them you get the phase boundary.

So, this is the isomorphous phase diagram ok.

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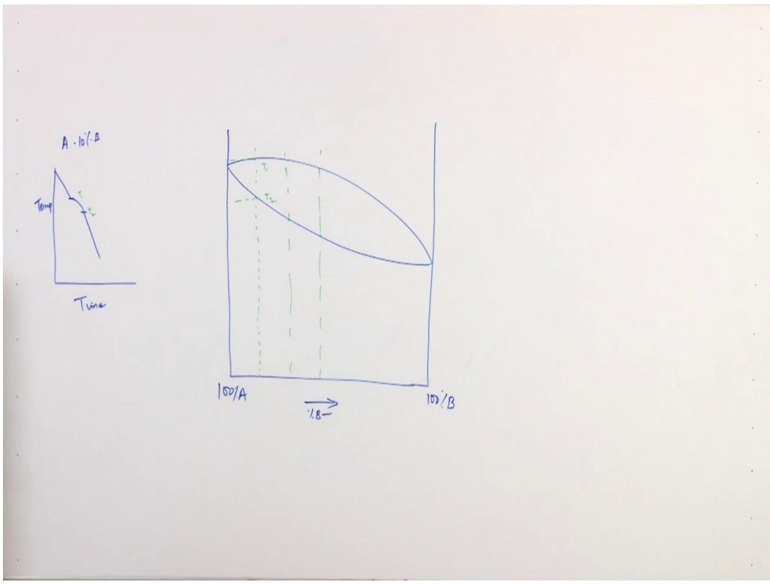

So, I will just use it to explain few things ok. So, this is composition is increasing at this point, I have 100 percent a. So, usually we say A B and so on. You can replace that by a particular elements. So, when if you are talking about copper nickel system, I will say it is 100 percent copper here 0 percent copper here, but 100 percent nickel here and so on. So, not talking about a specific system, let us say we are talking about any alloy which has A element and B element at this point it is 100 percent a at this point it is 100 percent B. So, it is percentage B composition is increasing in this direction ok. So, as I told you that from that time temperature profile suppose I had take a composition A 10 percent, B 1 composition I selected and then I noted down the temperature as a function of time ok.

Suppose this was the cooling in the liquid phase then the transformation started and then the cooling in the solid phase ok. So, I got these 2 temperatures here for 10 percent B suppose I have taken alloy here of 10 percent B let us say this one ok. So, I have got these 2 temperatures T 1 and T 2. So, these are the 2 temperatures here T 1 and T 2 ok. So, I got for this particular composition I got these 2 points ok. So, similar experiment you will do for other composition let us say I take 20 percent B, then I take 30 percent B at or for all these I will get from the time temperature profile temperatures and if I start plotting and then I join them I can get the complete phase diagram between these 2 systems.

So, this is how you get the phase diagram one of the method not the only method, one of the method to get the phase diagram. Now once I have got this phase diagram ok, I can see that there are other information which I can take out from it, let us remove some of this from here.

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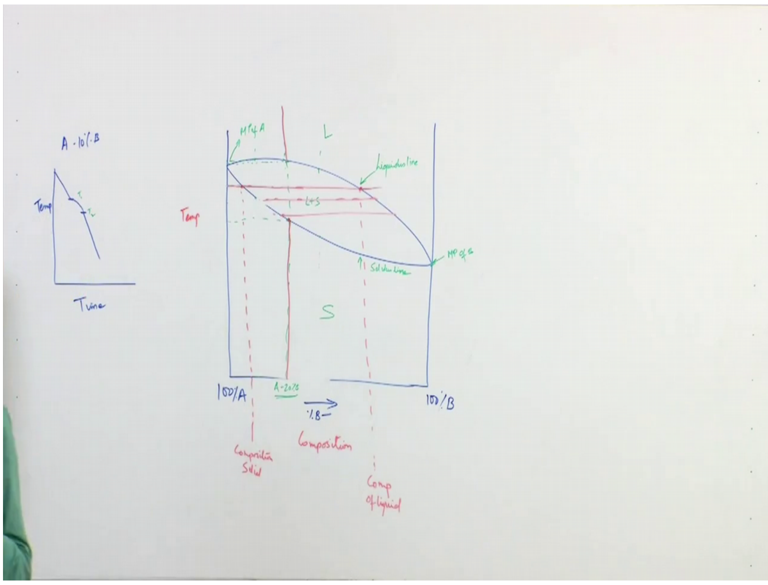

So, this is my 100 percent B ok, this is my liquid phase, this is my solid phase and in between all whenever there is a phase transformation in between always there is going to be 2 phase system ok. So, here I will have liquid plus solid in equilibrium. So, 2 phase coexist in equilibrium in between 2 single phase region now this is 100 percent a means pure a or let us say if you talk about copper nickel if it is pure 100 percent copper.

So, you can see that at 100 percent copper I will get the melting point of that particular component. So, this is the melting point of melting point of A. Similarly this is 100 percent B. So, this will be your melting point of B from here it goes from solid phase to liquid solid phase to liquid because these are pure and there is not going to be any 2 phase region at this points for any other composition there is going to be 2 phase mixture. So, liquid plus solid and solid now as I told you we discuss few terms you have a 2 boundaries here ok. So, we said that a boundary between a liquid phase and liquid plus solid phase will be called as liquidus line boundary between liquid plus solid and the solid will be called as solidus line.

So, we gave from this we get at for a given composition ok, I have to fix a composition for a given composition here at what temperature the solidification will start at what temperature the solidification will complete and then the solid phase will start below that particular temperature ok. So, few things, we can see we can get from this particular phase diagram now I will show give you. So, some there are a couple of more terms which will be helpful for us to get information from the phase diagram if you remember the first slide we said that there is a lot of information which you can get from the phase diagram ok.

So, there are 2 things which we can use to get the information about the phases present in the phase diagram one of the idea or one of the term which we use is called tie line, ok.

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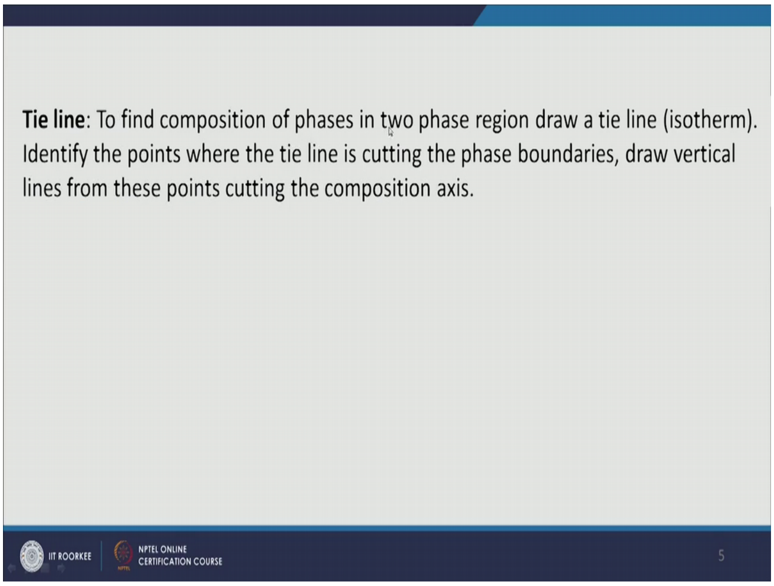

What is tie line if I want to find out the composition of phases in 2 phase region, I have to draw a tie line tie line is nothing, but a isotherm. Isotherm means at a constant temperature if I am taking something, then it is a isothermal condition then I have to identify the points where the tie line is cutting the phase boundaries draw vertical line from these points cutting the composition axis ok. So, now, my interest is suppose I have taken an alloy let us say I have say that this is my A 20 percent B alloy.

So, in this alloy 80 percent is A 20 percent is B, it can be weight percent it can be atomic percent I am not going into that detail right now ok. It can be weight percent for simplicity that I am took A 80 percent, let us say I want to make a one kg alloy ok. So, I have taken, let us say if I have to make a thousand gram alloy I will take A 800 grams of A 200 grams of B ok, may mix melt with them together and then I will get 1000 grams of alloy ok. So, that is what I have done I am I made an alloy, I took it in to the molten condition found out the temperatures at which the transformation starts and transformation is complete and from there you have got this information ok.

So, this is the overall composition of the alloy, now I want to know that what is the composition of the liquid phase and what is the composition of the solid phase as a at a particular temperature. So, at this particular temperature my transformation starts at this particular temperature it is over ok, suppose at this particular temperature ok, I want to know that what is the composition of the liquid phase what is the composition of the solid phase ok. So, what I will do I will draw a tie line ok, a tie line is the isotherm; that means, it is to be drawn at a constant temperature this is my temperature this is my composition.

So, I will draw a tie line which will be parallel to the composition axis isotherm will be parallel to the composition axis and now this wherever it is cutting these 2 phase boundaries that will give me the composition of each of this phase ok. So, if I want to know what is the composition of liquid phase? this will be the composition of solid phase and this will be the composition of liquid ok. So, you can see that overall complete composition is A 20 percent B the composition of solid is less than that.

So, maybe it is around you can say it is A 10 percent B for example, and composition of liquid will be let us say it will be a 70 percent B ok. So, in between during the solidification there will be lot of separation of B atoms between solid and liquid phases ok. So, initially the liquid is what we say solute rich the solid is solute poor or deficient as you keep on going to lower and lower temperatures we can keep drawing tie lines like this at the temperature where the transformation is completed there if it is done in a very slow rate in equilibrium condition the last when the total solid is forming and there is no liquid left, then the last total solid will be solidifying with this overall composition with which we started.

So, in the liquid phase, it started from here then the separation of solute atoms started between solid and liquid ok, it keeps on going and then the last when the solidification is completed, the whole solid is having the same composition is the overall composition, but this is the only possible when you are doing it a very slowly, as you can see understand that the first initial solids which are formed had very low percentage of B and as we keep coming the solid which is forming as high concentration of B.

So, we have to give enough time for this solute atom the B atoms to diffuse within the solid and have the homogeneous overall homogenous composition ok so, that when my solidification is completed the full solid volume will have only one composition ok. So, this is what do we mean by equilibrium solidification or the solidification which is following the equilibrium phase diagram ok. So, tie line I can use to find out the composition at intermediate levels ok. So, to find out the composition of solid phase here wherever the tie line is cutting the solidus line that will give me the composition of solid.

Wherever the tie line is cutting the liquidus line that will give me the composition of liquid then there is a another very important concept called lever rule ok. So, maybe you know few things from here.

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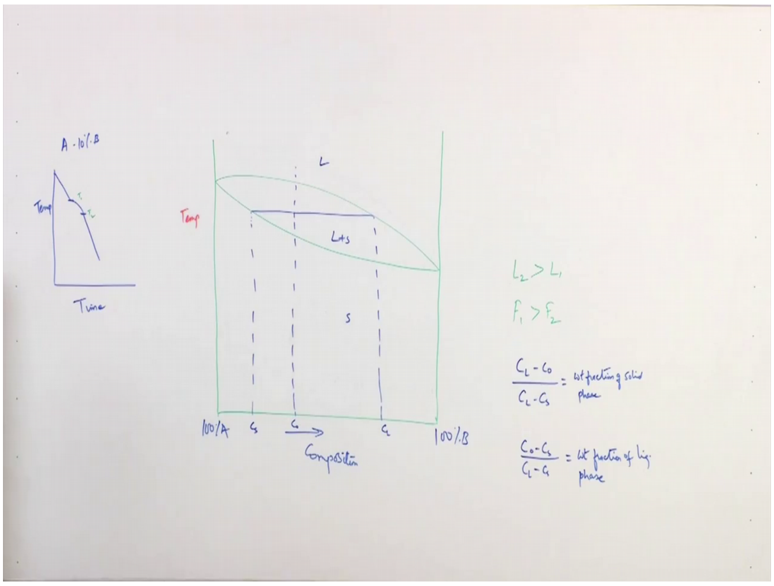

I will just remove this sorry. Now, again I can take a tie line here ok, as we just discussed and suppose I am taking a composition like this is my 100 percent A, this is my 100 percent B this is how my composition of B is increasing and this temperature and there is a tie line.

Now a one thing we have already seen that I can get the composition of each phase ok. So, this is liquid liquid plus solid and solid. So, this will give me the composition of solid and this will give me the composition of liquid see I can see say C L and I can say C S and this is the overall composition C naught now there is a concept in mechanical systems also which is called lever ok. So, when you have a lever you have A, if you have a fulcrum on which this lever is balanced ok, I can balance it like this can be called as lever there is a fulcrum there because I am trying to balance ok.

So, basically when I am trying to balance if I take a larger arm length here then I have to put more force here you can see that it is going down there. So, I have to put a force here a larger force here and that force will be in proportion to what is the length of the arm on both the side of the fulcrum ok. So, when the arm length is more here I have to put more force here ok. So, there is to have a balance in this lever arm if I have a larger length here my force F 1 will be more.

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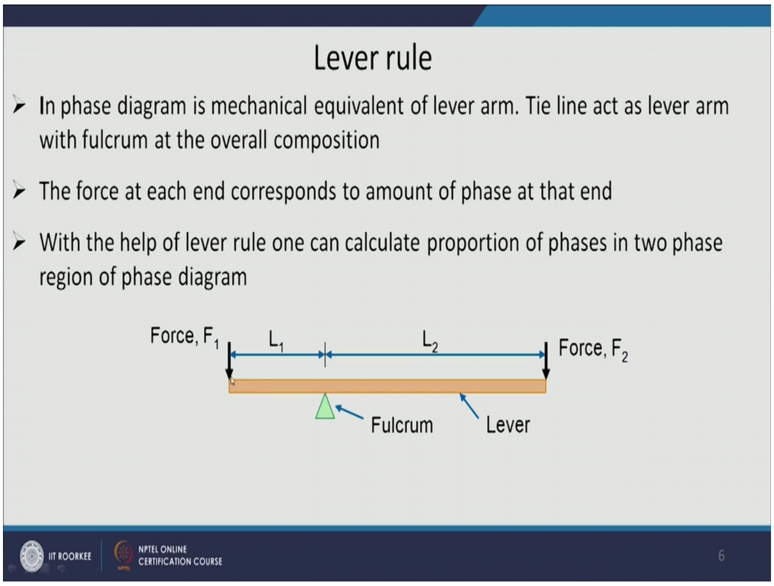

So, if L 2 is greater than L 1 to keep it in equilibrium or in balance ok, I have to have a larger force F 1 compared to force F 2.

So, in this particular diagram which is given on the slide L 2 is more than L 1 ok. So, my F 1 has to be more than F 2 and the proportion in which it has to be more will be in the same proportion in which the L 2 is more than L 1 ok. So, their proportion has to be same. So, in phase diagram tie line can act as a lever arm with fulcrum at the overall composition. So, where you have overall composition there can be a fulcrum, you can see that it looks like a lever arm fulcrum can be at the overall composition the force at each end correspond to amount of phase at that end.

So, what is the fraction of this phase and what is the fraction of this phase will depend will can have an equivalence with the force at this end. So, if my arm length is more here I will have a more force here; that means, I must have higher fraction of this phase I have a smaller arm length here. So, I will have lesser force here. So, this phase will have a smaller fraction with the help of lever rule one can calculate proportion of phases in 2 phase region of phase diagram. So, from the phase diagram in the first slide we said we can find out what are the different phases present in the phase diagram that now I can tell you have liquid phase liquid plus solid.

I said that we can find out the composition of each of the phase. So, if I have taken a certain composition in liquid phase it has composition of C naught in liquid plus solid region it has a solidus composition of C S liquidus composition of C L. Now I also want to find out what is the fraction of each phase for which I am going to use lever rule ok. So, if I want to know what is the fraction of the solid phase in this 2 phase mixture what I will do is I will take the arm length here which is which will be given by C L minus C naught that will give me the arm length here and that I will divide by the total lever arm which will be C L minus C S and this will give me the suppose this whole phase diagram is in fluid fraction what will be the weight fraction of solid phase.

If I want to know weight fraction of the liquid phase then I have you have to take this arm length. So, this will be now C naught minus C S divided by total length C L minus C S total length this will give me the weight fraction of liquid phase ok. So, I can now find out what will be the fraction of each of the phase also or if I have the weight fraction of solid phase if I subtract this from one or a 100 percent then I will get the weight fraction of liquid phase. So, if you calculate one also you can easily calculate the other by subtracting out of 100 percent or you can say if it is in fraction then out of 1 1 minus weight fraction of the solid phase will give you the weight fraction of the liquid phase ok.

So, I can use this analogy of mechanical lever to find out the fraction of each of this phase and then we will use this when we will do the assignments we will use this to find out all this information from the phase diagram with that; I will say thank you and in the next lecture, we will try to see other types of phase diagram this was a isomorphous phase diagram where the 2 component has complete solubility, but there are other phase diagram or systems where the solubility is not complete then what type of phase diagram you get ok.

Thank you.