Materials Science
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Lecture 18
Phase Diagrams

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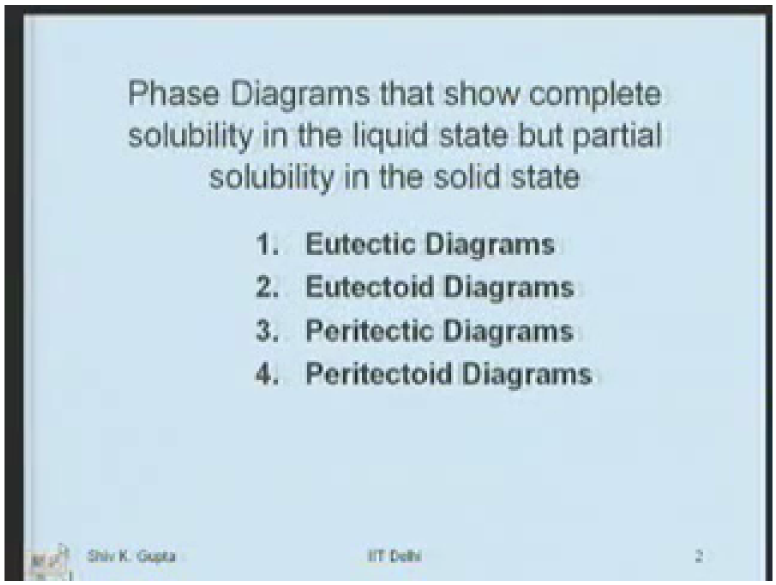

Well we were talking about the phase diagrams and we had looked at the isomorphous system among the binary diagrams. Next we want to look at diagrams which show complete solubility in the liquid state but do not show complete solubility in the solid state. And that is what we had written that there could be four kind of diagrams which are of this nature: eutectic diagrams, eutectoid, peritectic and peritectoid. We shall start with eutectic first and see the other ones as we go by.

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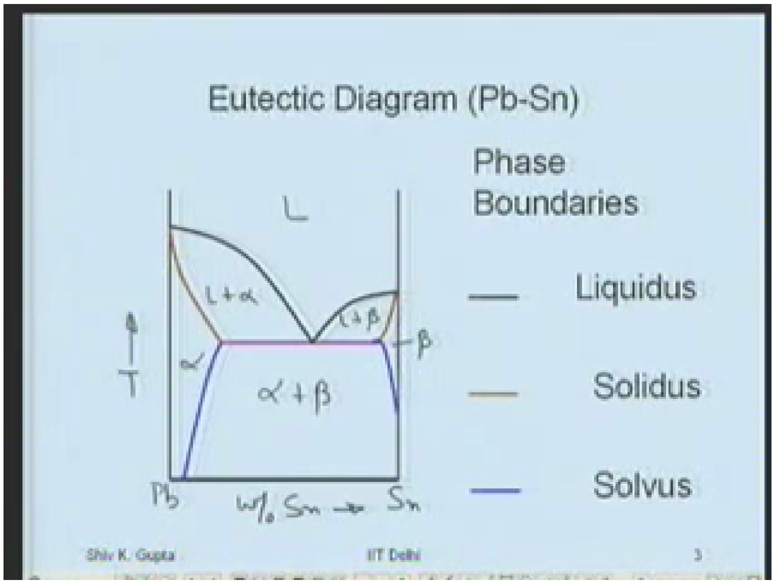

And before we finish the last class, we did show this diagram of lead and tin. Now I have already defined liquidus, this is black lines. The solidus, this is brown lines and solubility limit given by solvus lines which are blue. The thing which are not defined was what is this line in the middle which is horizontal line, we shall look at that next.

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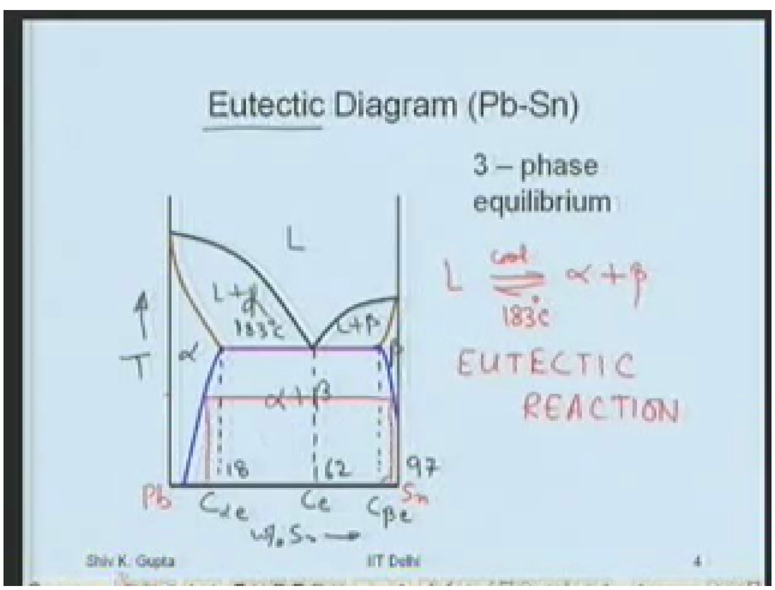

This line which is a common line is horizontal line and is, we can consider it to be a common tie-line between this liquid plus alpha region, liquid plus beta region and alpha plus beta region. This is the 3-phase equilibrium where alpha phase of this composition which, so here C alpha e, this composition of the beta phase called C beta e and this composition of the liquid phase called Ce. There are three phases which are in equilibrium: alpha phase, liquid phase and the beta phase. And this is the temperature which is constant, is 1,083 degree centigrade.

“Professor-student conversation starts.”

Student: What is this subscript e refer to?

Professor: Eutectic. Now this is the 3-phase equilibrium where three phases and their compositions evolve. C alpha e in this diagram is 18 percent of tin and C beta e is 97 percent of tin and Ce, 62 percent of tin. Of course, this say the temperature on this axis. Now the, if you look back your table where I showed you how many variables are there when three phases are in equilibrium in a binary system, for each one I have to define the composition, so three composition variables and the temperature. Pressure we have already exercised our degree of freedom, we kept at 1 atmosphere. Isobaric diagram these are and therefore I have the four variables.

Four variables are composition of the alpha phase, composition of the liquid phase, composition of the beta phase and the temperature. All four are fixed. That is how they are shown in this diagram just by a horizontal or a line parallel to the composition axis, a constant temperature line, temperature is fixed. On this there are three equilibrium or three compositions or the three phases which are in equilibrium is shown.

Student: So four variables are composition of alpha, composition….

Professor: Composition of alpha, composition of the beta, composition of the liquid and the temperature. All four are fixed. The degree of freedom is 0.

Student: Ce is, is not Ce the composition of the whole?

Professor: No, I never said that. Composition of the liquid phase which is in equilibrium with the alpha phase and the beta phase at this temperature. I have not talked about the overall alloy composition yet. So these are the three compositions or three phases and the temperature at which they are in equilibrium and this 3-phase equilibrium we write like this, liquid on cooling go to alpha and beta. Temperature is 1,083 degree centigrade. Alpha here is the lead rich phase and beta here is the tin rich phase and of course the liquid is the liquid of 62 percent tin.

So cool means here not lowering the temperature, extracting the heat. Heat is extracted in that direction. Liquid will go to become a mixture of alpha and beta. If it is heat is given to the system, alpha and beta shall melt to become liquid. Okay. This is like what is happening when water is solidifying at 0 degree centigrade. If you extract heat from the water, it becomes ice. If you give heat to the system at 0 degree centigrade, temperature is not changing, give the heat, ice melts and becomes water. That is exactly what is happening. Here instead of becoming one single solid, it becomes the mixture of two solids and two are of different compositions. This is what is called eutectic reaction or invariant reaction.

Student: Sir, how to distinguish between alpha and alpha plus beta? Why there is this solvus boundary? There cannot be just one, alpha plus beta all around, all through. Why there is distinction between alpha and beta and alpha plus beta?

Professor: Why these is a distinction between……?

Student: What does the solvus signify? Solvus.

Professor: Solubility limit. If I want to read the 2-phase region, as you recall we have to first draw a tie-line. Let us say I want to read at this temperature, I draw two constant temperature line which is called a tie-line in this 2-phase region. This gives me the composition of the alpha phase which is in equilibrium with the beta phase, that is the composition of the beta phase. We cannot forget what we have learnt in the last class.

This is how we read the 2-phase region. Right, 2-phase region, 1-phase region, I am not repeating the phase rule again. That works the same way. Only the 3-phase region where there is no degree of freedom left, the four variables, all four variables are fixed, is what I have discussed here. Is this clear? All right.

“Professor-student conversation ends.”

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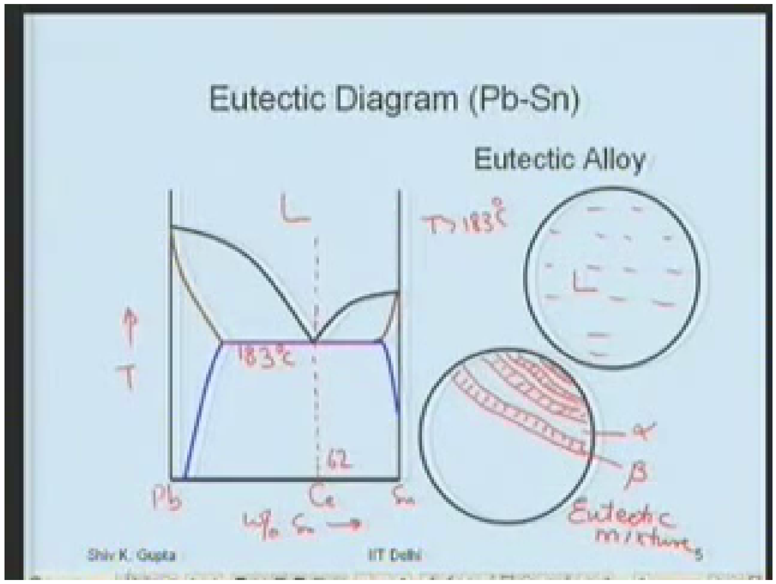

Now let us look at the solidification of this alloy which is called eutectic alloy, is the alloy with this composition which is the liquid composition in equilibrium at the eutectic temperature, is called eutectic alloy. And I told you it is 62 percent tin. This alloy, let us see above 183 degree centigrade what is happening to this alloy. It is in the liquid phase region, is above both the liquidus lines which are given here. So it is a liquid phase and at that temperature, temperature greater than 183 degree centigrade this is all liquid, liquid phase field is there.

But at 183 degree centigrade when it cools, means the heat is extracted, it becomes a mixture of alpha phase which has this composition and beta phase which has this composition. Now let us say this region alpha phase forms. So this region here gets depleted in lead and here also it gets depleted in lead, so that becomes a region in beta. Let us put beta like this which is rich in tin. Like that alternately I get lead rich and tin rich phases. That is the mixture of alpha and beta. This white region is alpha and that is beta.

“Professor-student conversation starts.”

Student: So it is necessary that liquid should be at the composition of 62 percent for this reaction?

Professor: Yes, it is important that it should be at 62 percent, then will be all solid alpha and beta mixture. These two phases, alpha and beta which are forming like this, I will be able to see them distinctly provided under the microscope when I see this distance between these two lines is at least 0.1 millimeter after magnification. Our resolution of the human eye is 0.11 millimeter. If it is less than 0.11 millimeter, I cannot see these two as distinct lines.

“Professor-student conversation ends.”

And similarly this region should also be more than 0.11 millimeter if you want to see it as distinct. Otherwise any two lines which are less than 0.11 millimeter away will look a single line. At times when these distances are usually small because atoms have to migrate and one time lead have to cluster together, other place tin have to cluster together, they may not be able to go to very far distances.

And even in a microscope, under the microscope when the magnification or the range of 600 to 1,000, I may not be able to see them as separate regions, whole thing will look as one dark region and is called a micro-constituent. Only when I further magnify, go to the electron microscope, I am able to see these two as distinct regions. So that is a mixture of alpha and beta. This is called eutectic mixture. This eutectic mixture of alpha phase and beta phase is a micro-constituent, is not a phase. There are two phases, alpha is one phase, beta is another phase. That is why I am calling it a mixture. It is a mixture of two phases, alpha and beta.

And under the microscope when I see magnifications like 600,000 times, I see only one dark region, not always, sometimes I am able to see them separately also. We will see them as distinct regions in the laboratory when you go to see one of these alloys. That is what is called eutectic alloy and on solidification it becomes a mixture of alpha and beta.

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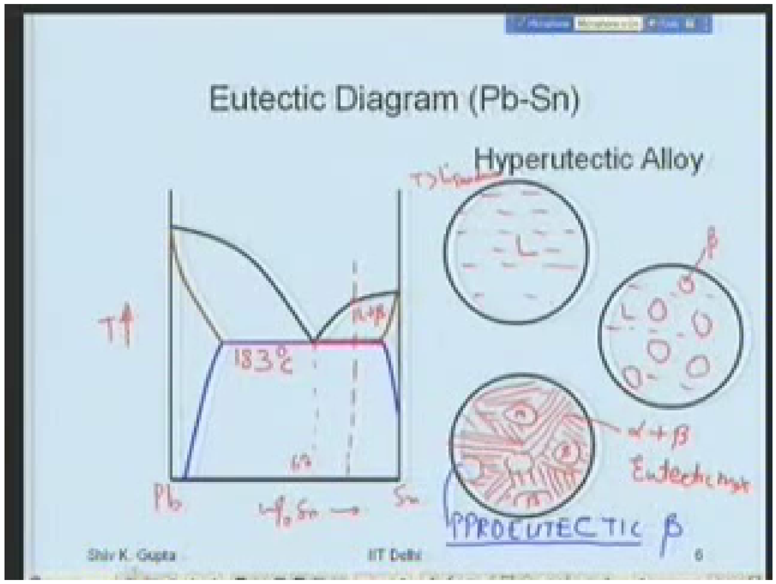

Now let me take an alloy which is hypereutectic. Hypereutectic means the composition of the alloy is more than the eutectic composition. Again I have written this as alphabetically, lead and tin. This is the eutectic composition which is 62 percent tin. Hyper means more than 62, that means on this side. This alloy is hypereutectic alloy. All compositions having tin cum greater than 62 percent will be called hypereutectic.

In this alloy when I am above the liquidus, that is above this temperature, temperature is greater than liquidus temperature, is going to be all liquid. But when I come below liquidus but above 183 degree centigrade which is the eutectic temperature, I am in the 2-phase field, liquid and beta. Beta begins to form in liquid and this keeps on till I reach the just above 183 degree centigrade. When I reach just above 183 degree centigrade, what is the composition of the liquid and what is the composition of beta phase which I have floating in the liquid?

I have to draw the tie-line there. Composition of the beta phase is this which is 97 percent and composition of liquid phase is this which is 62 percent. But I have just reached just above 183, 183.01 degree centigrade let us say. So the liquid now is of 62 percent tin which is eutectic liquid with eutectic alloy. Now when you extract heat at 183, what happens? This liquid becomes a mixture of alpha and beta, what is called eutectic mixture.

So by the time I reach just below 183 degree centigrade, I have all these beta particles which formed at temperatures greater than 183 degree centigrade and remaining region the liquid gets filled with the mixture of alpha and beta which is called eutectic mixture.

“Professor-student conversation starts.”

Student: Then what will be the composition of this mixture?

Professor: Which one?

Student: Eutectic mixture. Beta will be…..

Professor: See this is beta which form at temperature greater than 183 degree centigrade. And this is a mixture containing alpha and beta, they form at the eutectic temperature and therefore I call it eutectic mixture. So to distinguish this beta from that beta, see the beta which forms on solidification has the same composition 97 percent and alpha which forms has 18 percent. So mixture also contains the same beta, beta is beta, physically same. Same lattice parameter, same chemical composition which is in equilibrium at that temperature.

But one is forming globules, other one is part of the mixture. The difference is the one which is a globule, this form at temperatures above 183 degree centigrade when liquid was solidifying and the one which is the part of the mixture, that formed at temperature 183 degree centigrade. So we differentiate them by calling them differently. These globules are called proeutectic beta, is called the proeutectic beta.

While this is the part of the mixture, is called eutectic beta. Eutectic alpha, eutectic beta, they are forming the mixture which is called the eutectic mixture. But there is no difference as well as crystal structure is concerned, chemical composition is concerned, the looks of the beta phase is concerned, its properties are concerned, they will be exactly same. Only difference is the temperature at which they are formed. In the mixture it forms at 183 degree centigrade. As globules proeutectic phase, it forms at temperatures greater than 183 degree centigrade. Is this clear? All right.

“Professor-student conversation ends.”

We talked about the lever rule. You can apply the lever rule at different places, different temperatures and you will notice that it is not possible for you to apply the lever rule at 183 degree centigrade. You can apply the lever rule in a 2-phase region above 183 degree centigrade, below 183 degree centigrade but you cannot apply the lever rule at 183 degree centigrade where three phases are in equilibrium.

Now let us talk about the solidification of water at 0 degree centigrade, 1 atmosphere. You are cooling it and water is freezing slowly, becoming ice. Can at any time you tell me how much is the ice and how much is the water? It is a dynamic process. It starts with 100 percent water. As heat is extracted, it goes to heat, all the latent heat of fusion is extracted, it becomes all ice. So there is another parameter required to do the mass balance, how much heat has been taken out or how much heat has been given to the system.

That is why it is not possible to do the mass balance at 183 degree centigrade because one more parameter is missing. How much liquid we have extracted the heat to become solid. So therefore lever rule cannot be applied, the mass balance cannot be done at 183 degree centigrade in absence of that knowledge but it cannot be done above 183 degree centigrade. It can be done below 183 degree centigrade because there the equilibrium is not dynamic, here the equilibrium is dynamic, changing with time depending upon at what rate the heat is given or heat is extracted. Is that clear?

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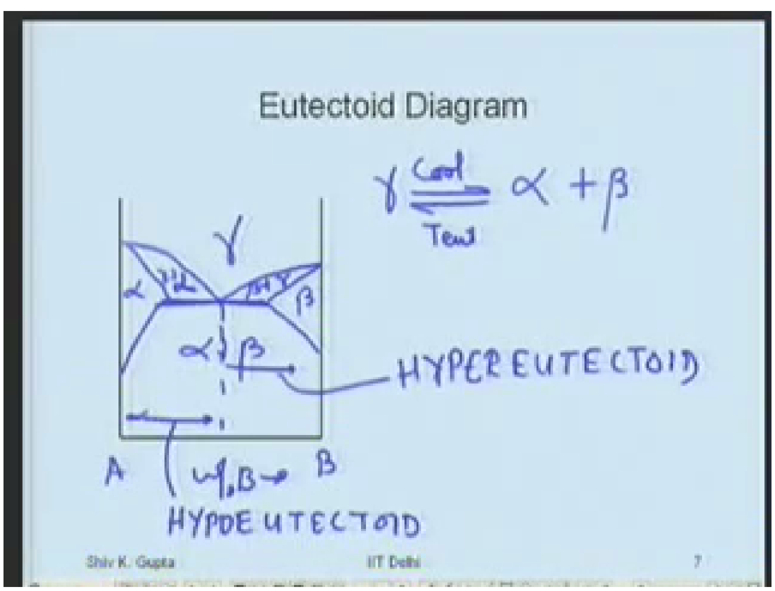

With this we move onto the another kind of diagram which is similar to the eutectic diagram because the name also suggest eutectoid. Only thing is there is no liquid phase here. All three phases involved are solid phases. Gamma on cooling go to become alpha and beta and that is the eutectoid temperature at which it happens. So diagram looks something similar to what I have already described.

This is gamma phase, this is alpha phase, that is the beta phase. This is alpha plus beta phase. That will be gamma plus liquid and this will be beta plus (liq), sorry, beta plus gamma. And this is gamma plus alpha. There is no liquid phase involved. And this could be A, this could be B and that is the weight percent B. That means melting point is somewhere up higher, it is happening in the solid state. Reaction similar to the eutectic happening in the solid state is called eutectoid diagram. Similar to what we talked about the hypereutectic, (hyper) hypoeutectic, we have all the alloys to the left of the eutectoid compositions called hypoeutectoid alloys.

And the ones here on the right are called hypereutectoid alloys. Okay. Well, it is quite similar to what we have talked about the 3-phase equilibrium also very clear, the four phases, four parameters, the composition alpha phase, gamma phase, beta phase and the temperature, everything is fixed.

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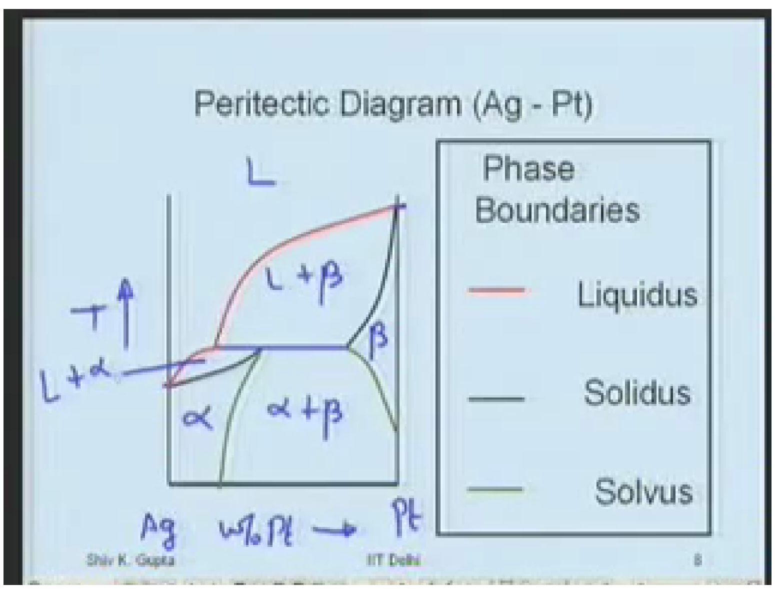

All right. Then we have another kind of diagram, peritectic diagram. In here there is a slight difference as compared to what we discussed as the eutectic diagram. This is a sliver platinum diagram. I have taken example of sliver here, platinum here, weight percent platinum is shown on the x axis, temperature on the y axis. This is the melting point of silver, that is the melting point of platinum. This is all liquid, this is liquid plus beta. This region is liquid plus alpha. This region is alpha and this region is alpha and beta or this is beta.

1-phase, 2-phase regions you can talk in the same way like we talked in isomorphous system or the eutectic system. Usually what you notice here is the melting points are slightly, difference in the melting points a little higher in such systems usually. Silver is 920 and that for platinum is 1,900. You can see the temperature difference a little larger. And 3-phase equilibrium is shown here where the temperature is fixed. Composition of the liquid phase, composition of the alpha phase, composition of the beta phase, they are all fixed at this temperature.

And the phase boundaries like we talked about the eutectic diagram, this is the liquidus line, that is another liquidus line. This is solidus line, that is also a solidus line and this is solvus line, solubility limit it gives. That is the solvus line, it gives solubility limit. And that is the 3-phase equilibrium here. That is the major thing, only thing the shape of the diagram, the lines which are going are different. Otherwise you can apply your 1-2-1 rule, you can look at the phase rule and you can apply the lever rule in 2-phase regions easily. And the way we read the 2-phase region is you have to draw a tie-line and read the 2-phase which I explained just now.

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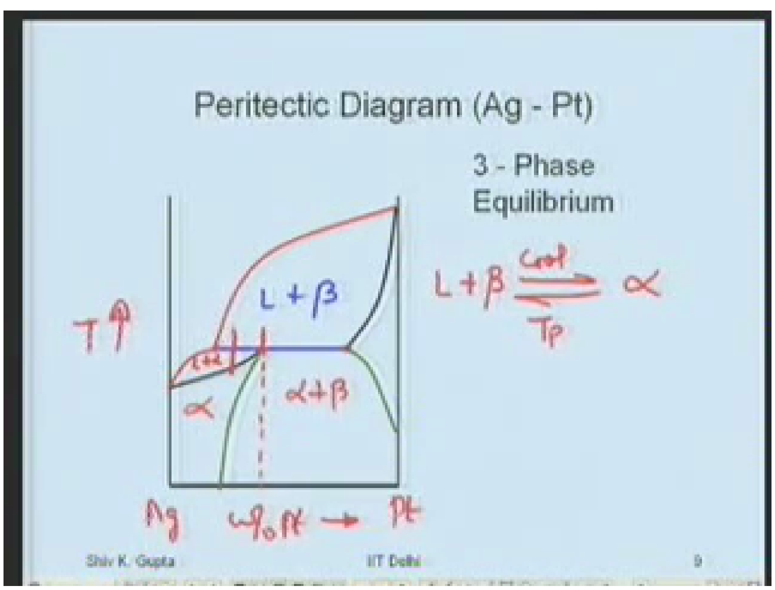

Now the 3-phase equilibrium here is at this temperature and it is written like this because what is happening just above this temperature if you look at, you are in this region where you have liquid and beta. So we write this as liquid and beta on cooling at peritectic temperature go to form alpha. This is the alpha phase field, so it is this composition you see. I take the liquid of this composition, I take the beta of that composition which is there and then I solidify this. It is the alpha I get of this composition. That is the reaction. So if you give the heat, alpha will go towards the liquid and beta.

If you, and the compositions of course you can read here on the 3-phase line. So that is the peritectic diagram. Of course, here we have the temperature, melting points and the silver here, platinum there and weight percent platinum. You can similarly take any alloy, cool it and see how the microstructure is changing. Microstructure will change going from liquid plus beta if you have alloy here and here the liquid will react with the beta to form the alpha. Plus there will be some beta remain unreacted because quantity of beta is more than what is required to react to form the alpha.

The quantity of alpha and, liquid and beta are just in right quantity. If I have overall alloy composition is the same as this, composition of the alpha phase here. If it is same composition, then just above the peritectic temperature, this is the amount of the liquid phase, this is the amount of the beta phase which are in right proportion to give me 100 percent alpha. If I am to the right, I have more of beta and less of liquid. So all the liquid reacts with beta to form alpha but some beta does not react and it is there unreacted. So I go into the alpha plus beta region.

Similarly if I am to the right, left of this, in here I have more of liquid and less of beta. So what happens is all the beta reacts to form alpha but all the liquid does not react. So I get into liquid plus alpha region. Only here I get 100 percent alpha and then as I decrease the temperature, solubility says that much platinum cannot remain in silver. So solubility limit is or the, it becomes supersaturated and second phase precipitates out. So that is the peritectic diagram. Similar to this is the peritectoid diagram but it is in this all solid state.

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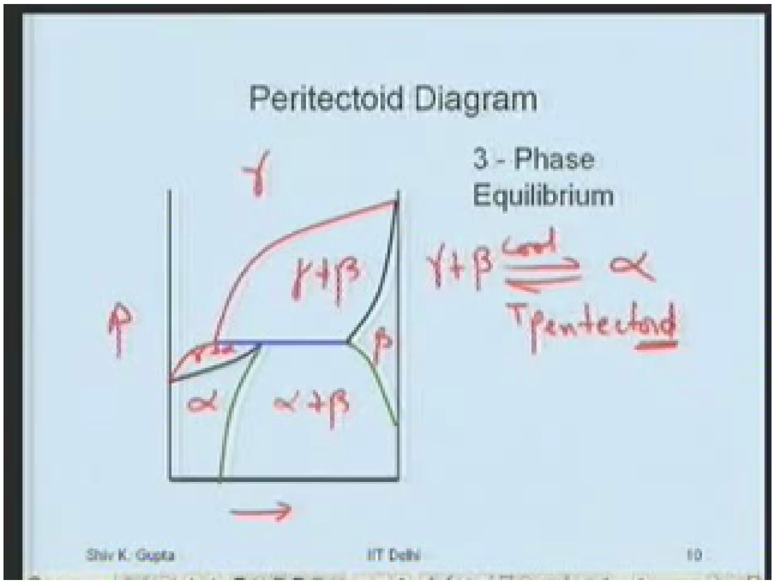

Yeah, in here I have this instead of liquid as another let us say as what I have here is a solid phase gamma, this is let us say gamma plus beta and this is, it becomes gamma plus alpha. This is alpha, this is alpha plus beta, that is beta. So the reaction would be gamma with beta reacts. On cooling forms alpha and that is the peritectoid temperature. See, oid at the end means there is no liquid phase. ic at the end means it is all, one, there is one phase which is liquid phase. Eutectic, peritectic have one liquid. Eutectoid, peritectoid have no liquid. Okay. All right. This is of course, you can write down what is this axis and that axis. That is the peritectoid diagram.

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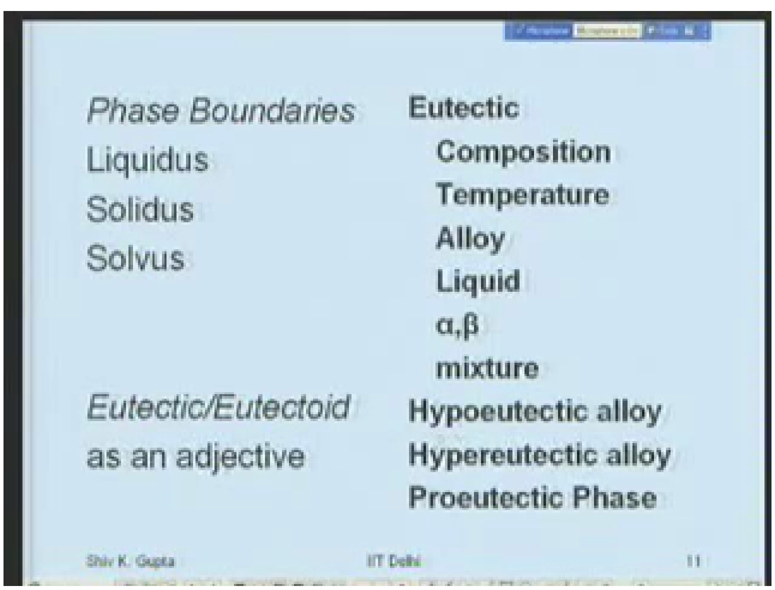

So before I proceed further, just write, I have written or summarized some of the boundaries and uses of the term eutectic, eutectoid. Phase boundaries we have talked about are liquidus, solidus and solvus. Liquidus at temperatures greater than this is all liquid. Solidus at temperatures below this it is all solid. Solvus gives the solubility limit. Eutectic and eutectoid are usually used an adjective, like eutectic composition, eutectic temperature, eutectic alloy, eutectic liquid, eutectic alpha, eutectic beta, eutectic mixture. These all must be clear to you by now.

Hypoeutectic alloys is again usage of this eutectic as an adjective with hypo. So is a suffix, is what is called, anyway hypereutectic similarly is eutectic is used as an adjective and proeutectic is the phase that forms at temperatures greater than the eutectic temperature. Okay. Here the prefix is hypo and hyper to the eutectic. So that is how the use of eutectic or eutectoid is taking place as an adjective.

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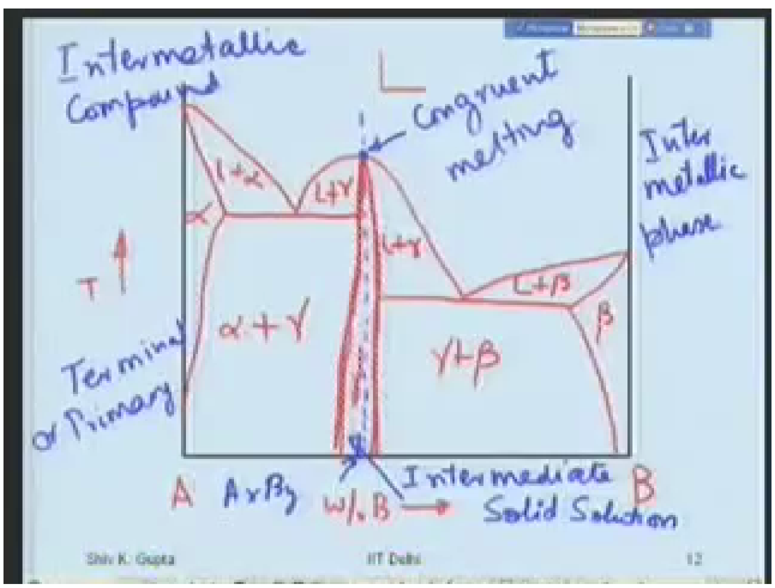

All right. Now I shall try to show you some complex diagrams which may have more than one 3-phase equilibrium present in them. Okay and then introduce a few more things which we normally observe. Let us say this is some A. I have weight percent B, this is B. Here I have temperature. Let us first sketch the diagram, then we will talk about it. This is a liquid phase field, alpha phase field, beta phase field. This is the liquid plus alpha region. This is the, let us say in between I have got this solid phase, let me name it gamma.

This is liquid plus gamma region. This is also liquid plus gamma region. This is liquid plus beta region. This is gamma plus beta region, this is alpha plus gamma region. You notice that this diagram if I draw a line (perpendi) parallel to the temperature axis passing through the temperature where this solid of this composition is melting at a single temperature like this, this is what I refer to as congruent melting.

I have three phases here which are solid: alpha, gamma and beta. Alpha you can notice that is pure A and some B is dissolved in it as solid solution. So beta is almost pure B but some A is dissolved in it as a solute. These are the solid solutions, alpha and beta are called terminal solid solutions or primary solid solutions. Terminal or primary. But gamma is also a solid solution of A and B. Restricted solubility of A and B both on this thing, but it forms in the middle of the diagram, it is not with close to pure A or close to pure B. This is called an intermediate solid solution.

This is also called an intermetallic phase or an intermediate phase. If this composition is very narrow, just very close to this line, I can even call it a compound. It may not be a chemistry compound, that is composition can always be written as AxBy. Ax is some fraction, y is another fraction. It can always be written like that. In that case I call it an intermetallic compound. When it does not show solubility limits, it is just very narrow which can be shown just by a single line, vertical line. And what you notice here, if I divide this along this line with compound I call this as let us say AxBy. On the left I have a phase diagram between A and AxBy, on the right which is eutectic diagram. On the right I have another diagram which is between AxBy and B and both are eutectic diagrams having different eutectic temperature.

So such intermediate phases or intermetallic compounds do form in various diagrams and it could, I have made both sides eutectic, it could be peritectic on one side and it could have been eutectic on one side. It is also possible. So such diagrams are also going to be there. And it could be then a reaction taking place in the solid state itself. That is also possible. Some of these diagrams we will come across.

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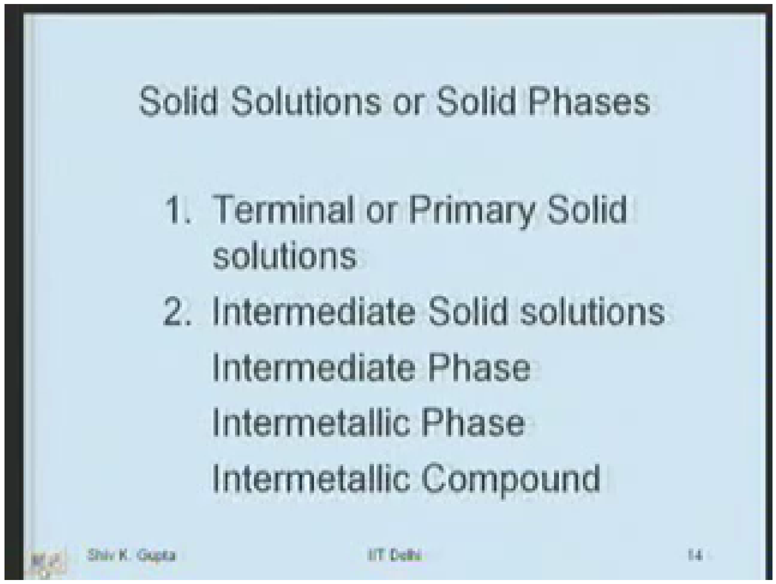

So we have talked about solid solutions or solid phases. Terminal or primary solid solutions like B dissolves in pure A as solute, it becomes a terminal solid solution or A dissolves in pure B, it becomes a terminal solid solution. Then we have talked about the intermediate solid solutions I showed you, (intermet) it also can be called intermediate phase or intermetallic phase and intermetallic compound if it is very narrow composition of solubility. Okay.

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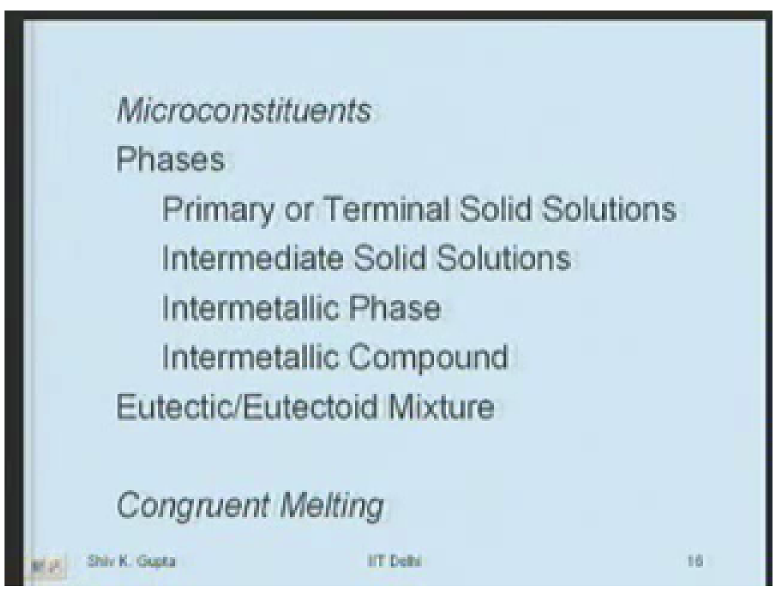

Well, the microconstituents in the diagram, we have seen the phases are primary or terminal solid solutions, intermediate solid solutions, intermetallic phase, intermetallic compound. Eutectic, eutectoid mixture, these are the mixtures we have seen and the congruent melting are some of the other things which I have talked about so far.

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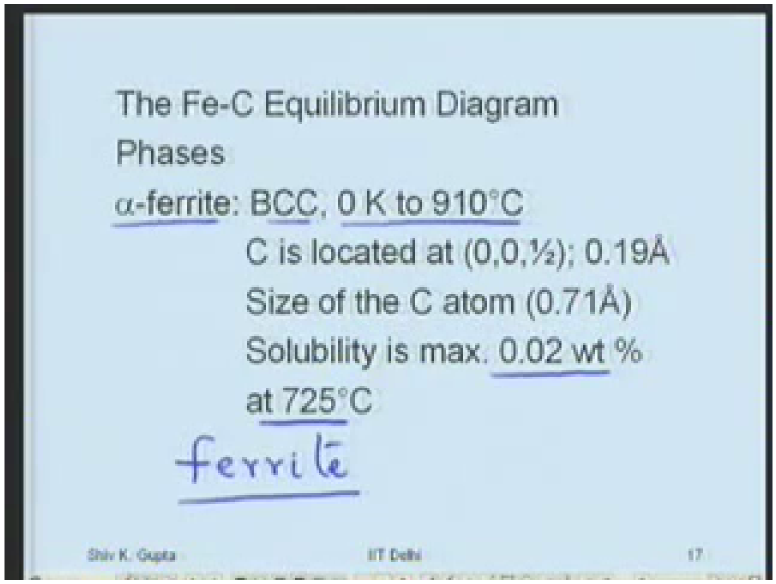

Now next we shall look at the iron-carbon diagram where one of the intermediate phase or intermetallic compound is very narrow composition range, as a matter of fact it is more or less a fixed composition and that is Fe3C. In this diagram what all we see, first of all we will discuss that and then we shall look at the diagram one by, step by step. In this diagram, iron-carbon equilibrium diagram, the phases which are present is alpha-ferrite which is a BCC crystal structure and it is stable between 0 kelvin to 910 degree centigrade.

I showed you that at 1 atmosphere in the unary diagram of iron. And carbon in the BCC is located 0,0,half. What is 0,0,half? Center of the edge where you can accommodate 0.19 angstrom diameter but the carbon size is 0.71 angstrom. So it strains the matrix and thereby solubility is very restricted to 0.02 weight percent and maximum is found at 725 degree centigrade. At higher temperature up to 910 and lower temperature up to 0 kelvin, it is much less than 0.02 weight percent.

0.02 weight percent will be roughly about 0.1 atomic percent, it is not a very large solubility. That is the alpha phase and sometimes simply called ferrite. This is phase, we simply call it ferrite, do not even say alpha-ferrite.

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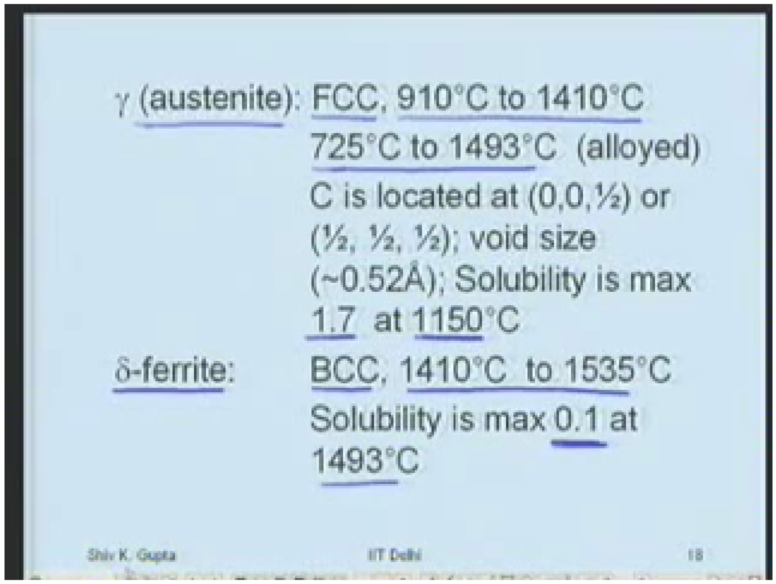

Another phase which we find there is gamma phase, what we call austenite. This austenite is FCC in crystal structure and is stable between 910 and 1,410 degree centigrade in pure iron. But in the alloyed state it is stable between 725 to 1,493 degree centigrade in the alloyed form. And carbon is again located at the edge centers or the body centers in this case. And void size gives me about, just about 0.52 angstrom though the carbon is 0.7. Solubility is little more but is maximum at 1.7 weight percent at 1,150 degree centigrade.

At all other temperatures from 725 to 1,493, it is less than 1.7 weight percent. 1.7 weight percent will be roughly about 7 atomic percent. Okay. Now the delta-ferrite is another one which is called delta phase or delta ferrite which is again BCC like alpha-ferrite. But stability range is between 1,410 to 1,535, both the alloyed state as well as in the pure form and it is the solubility of carbon is maximum at 0.1 percent at 1,493 degree centigrade. These are the three solid solutions and the phases which we see there.

“Professor-student conversation starts.”

Student: Sir….?

Professor: Yes, please. You can note it down.

“Professor-student conversation ends.”

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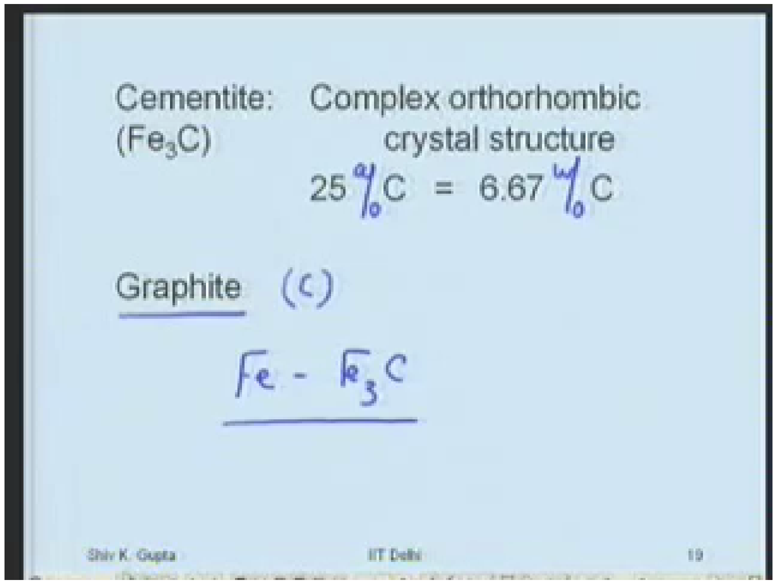

The next phase is the cementite, Fe3C. It is a complex orthorhombic crystal structure and from this you can see this 25 atomic percent carbon. Out of four atoms, one is carbon. So it is 25 atomic percent carbon. But if you work it out knowing the atomic weights of iron and carbon, it is 6.67 weight percent carbon. And it is a single composition compound, intermediate compound, intermetallic compound. It is not a chemistry compound. Fe3C is not a chemistry compound. Okay.

And also we find another phase which is present carbon which is in the form of graphite. In iron-carbon system I am talking about. Since Fe3C is a single composition and it melts at a single temperature congruently, the iron-carbon diagram can be given in Fe-Fe3C and Fe3C carbon. The reason for that is beyond Fe3C composition, that is beyond 6.67 weight percent carbon all alloys of iron and carbon are useless in the sense they are very, very brittle materials.

A small heat or small force coming, it will just crumble into pieces. And therefore material is of no use to us. And what are the useful steels and cast-irons, they are all less than 6.678 percent carbon. Even cast-irons do not have exceeding 4.2, 4.3 percent carbon around there. But can I, I can have 4.5 percent carbon in the big iron. So we look at the diagram between 0 percent carbon and 6.67 weight percent carbon and call this diagram instead of iron-carbon diagram, Fe-Fe3C diagram. And therefore you notice that iron comes before iron carbide, Fe-Fe3C, alphabetically you have seen that, are being placed.

And also sometimes we do not use this concept of going A on the left and B on the right depending upon my interest. Suppose my interest is on B, then I shall make A as a solute in B. My main interest is B. So B will be on the left in that case, not A. So there sometimes we have to give way to this concept. Otherwise we use on the x axis, alphabetically the components which are coming there.

“Professor-student conversation starts.”

Student: What is graphite? Why we should not……

Professor: Graphite is pure carbon.

Student: Carbon (())(47:05) graphite form.

Professor: Yeah, it is not in diamond form. Iron-carbon diagram I am talking about, I am not talking about the diamond.

“Professor-student conversation ends.”

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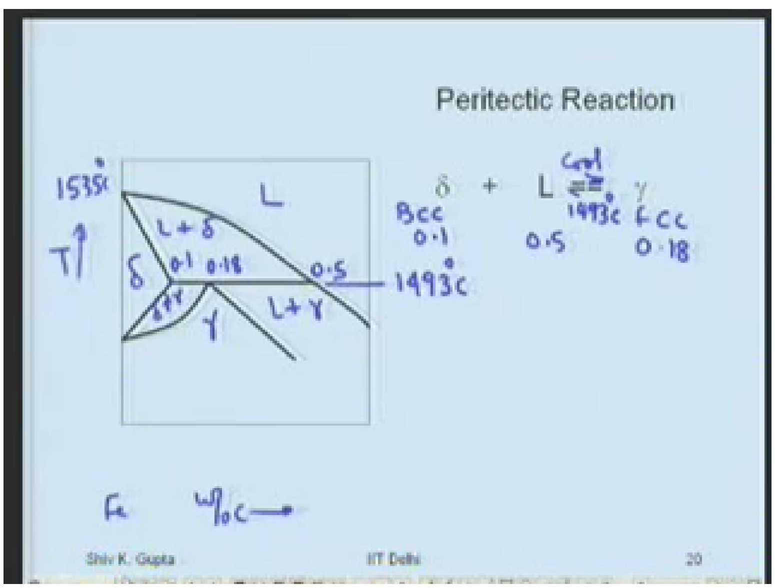

Now I shall show you the 3-phase equilibrium which are present. This is one corner, of course this axis is the temperature axis. This is the temperature axis. That is the melting point of iron, 1,535 degree centigrade. Of course, this is pure iron and it is weight percent carbon here. And this is the delta phase region, this is the liquid phase region. I have liquid and delta here. And you can see that this is going to form a peritectic reaction. And this is the gamma phase here. Delta plus gamma phase in here and liquid plus gamma phase here.

The composition here is 0.1 percent, this composition is 0.18 percent and this composition is 0.5 percent and this temperature is 1,493 degree centigrade. So you can say that delta plus liquid on cooling go to form gamma. Delta of course you know is BCC. Liquid has no structure. Gamma is FCC, the delta has composition 0.1 percent. Gamma has a composition of 0.18 and liquid has a composition 0.5 which are in equilibrium and the temperature is 1,493 degree centigrade. That is one peritectic reaction we find in the iron-carbon diagram. This is like the peritectic diagram, I have not shown the complete thing. This is the like the peritectic diagram we have.

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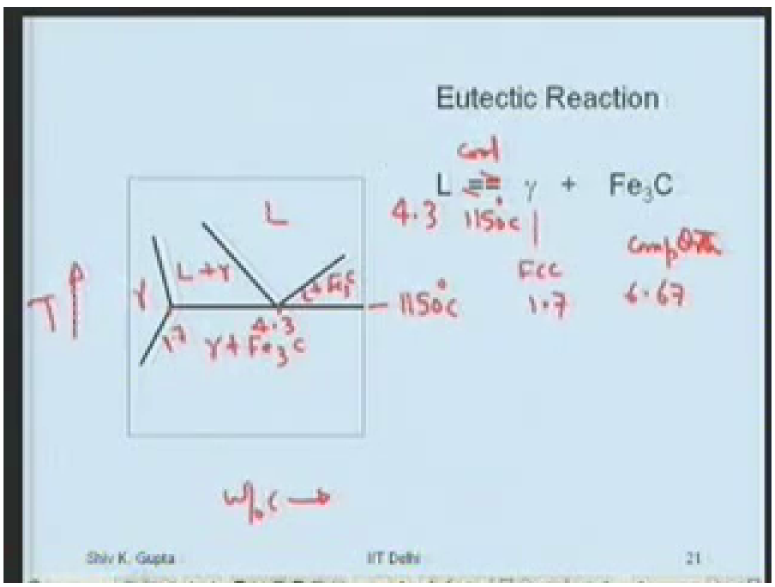

All right. Then we show the next, next 3-phase equilibrium is seen here. Again this is the temperature and this is of course the weight percent carbon what I write here. This is not pure iron here. This is liquid, and this is gamma phase field. Liquid plus gamma phase field here and this is the Fe3C plus liquid. And this is gamma plus Fe3C phase field. This temperature here is 1,150 degree centigrade. So I have eutectic reaction. Temperature is 1,150 degree centigrade. Gamma is again as I already said, FCC I have already described that. It contains here 1.7 percent carbon and Fe3C contains, is orthorhombic, complex orthorhombic and contains 6.67 weight percent carbon.

That is the eutectic reaction, the second reaction which is taking place at 1,150 degree centigrade. And this composition of the liquid, eutectic liquid is 4.3 weight percent carbon and Fe3C on the other hand will be 6.67. So this is how we can, all right, they have not stated, I can state this here 4.3 percent liquid is the composition. That is another 3-phase equilibrium we have in the iron-carbon diagram. And there is third 3-phase equilibrium which is in the solid state.

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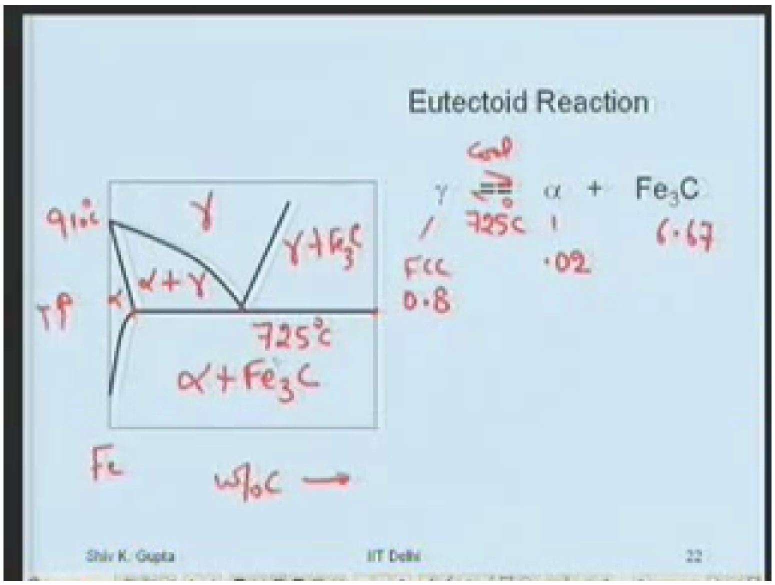

I shall look at that now. This is pure iron and this is the weight percent carbon. That is the temperature. This temperature is 910 degree centigrade here. This temperature is 725 degree centigrade here. This is the gamma phase field, this is gamma plus Fe3C phase field. This is alpha phase field, alpha plus gamma phase field and this is alpha plus Fe3C phase field. This is the most important of the three reactions or three equilibrium which we have in iron-carbon diagram. All steels are here. Whatever has happened at high temperature is all lost because we have all gamma. Above 910, I have everything gamma and steels are here.

These are all steel compositions and therefore this reaction is the most important reaction in iron-carbon diagrams. Gamma which is FCC, well the reaction is on cooling at temperature is 725 degree centigrade, it becomes alpha and Fe3C. Well, I have already told you gamma is FCC. The composition here is 0.8 percent carbon. Alpha is BCC, composition here is 0.2 percent carbon. And this is Fe3C at this end, it is 6.67 percent carbon.

Structures I have already told you that. That is the eutectoid reaction and is the most important reaction in the iron-carbon diagram. And all engineers must be aware of it because they are using variety of steels. More than 1,000 varieties of steel are available but this is the central diagram or central part of the diagram which is all the steels.

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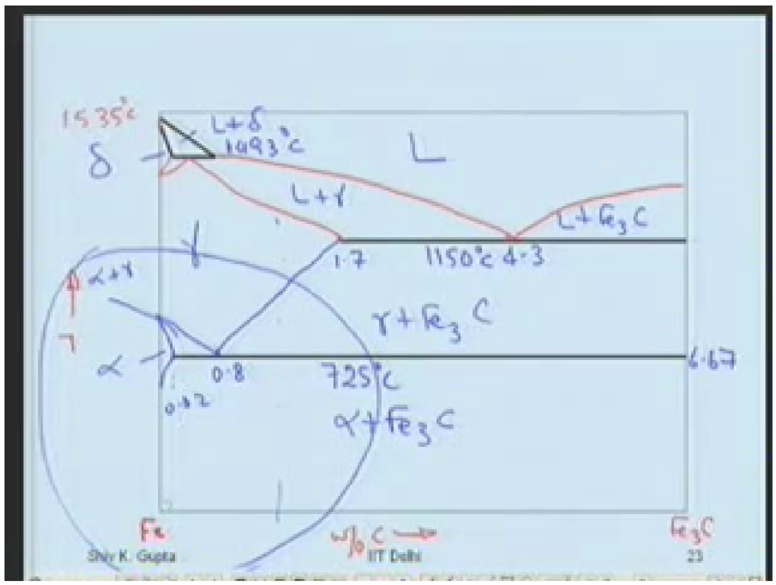

Now when I have put all these reactions, all the three reactions together, diagram looks something like this. You can find a line. So first of all, this is the peritectic reaction and here is the eutectic reaction. Now this here I have the eutectoid reaction. My diagram may not be to the scale, please keep that in mind. That is the liquid phase field while here is my alpha-ferrite. Here is my delta ferrite. This is my austenite gamma. This is, these are 2-phase fields, liquid plus delta, liquid plus gamma, liquid plus Fe3C and this is gamma plus Fe3C.

This is alpha plus Fe3C and this is here alpha plus gamma phase field. Well, compositions I have already told you, but important ones you must remember is 0.02, 0.8 and this is 6.67. This temperature is 725 degree centigrade, this is 1,150 degree centigrade and this is 1,493 degree centigrade and this composition is 4.3 percent carbon. It is 1.7 percent carbon. This is the iron-carbon diagram and that as I said already this is the most important part because steels have usually up to about 1.2 percent carbon in them.

So all these, whatever is happens here to the steel, all this reaction is all lost because it is a single phase now. What happened to the single phase when it goes to the eutectoid reaction is what is important. And that changes the characteristics and the microstructure of the steel. We shall see the microstructure of the steels in the next class.