Phase Diagrams in Material Science Engineering
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Lecture - 61
Case Studies on Ternary Phase Diagram – II

Students, today we are going to finish of this course by discussing the ternary phase diagram of silicon dioxide, aluminum oxide and magnesium oxide. Before that I would like to take about few minutes to discuss the stainless steel phase diagram, which is specifically nothing, but between iron chromium and nickel as you know stainless steels are actually steels with very low carbon concentration major alloying elements are basically carbon. So, basically iron chromium and nickel and for a typical stainless steel like 18-8, we add about 18 percent chromium and 8 percent nickel.

Therefore, almost about 75 percent is iron and rest of the things are that basically alloying elements. So, before actually for any ternary phase diagrams we need to know the binaries. This is something which you have probably seen in all my lectures, first thing we do always to consider the binaries between the components. So, in iron nickel and chromium system there are three binary systems between iron, nickel there is a container solid solutions existing from nickel region to very close to iron, but at about 4.6 percent nickel as you see here.

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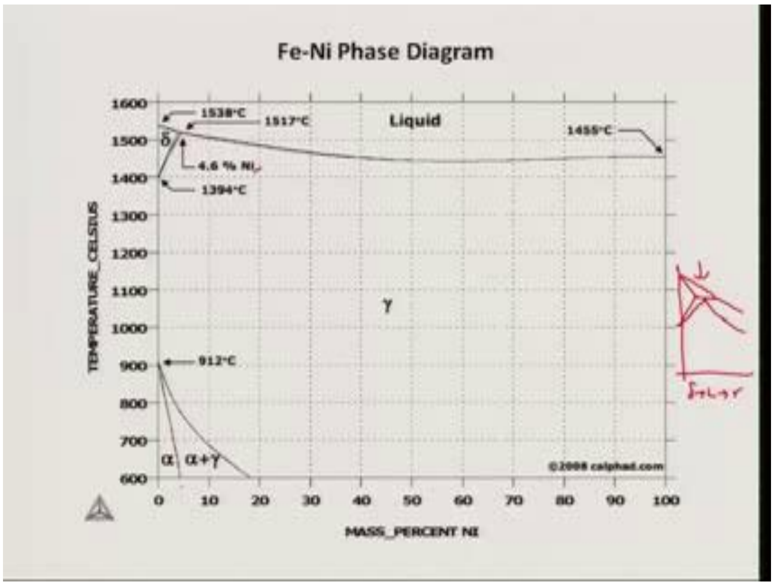

And 1517 degree Celsius temperature there is peritectic reaction, although it is not clear it is like this you know very small peritectic reaction taking place. So, this is how the phase diagram looks like. So, this is what I am talking about, this is peritectic reaction existing at this temperature this is nothing, but delta plus liquid going to gamma same as iron carbon iron phase diagram also, but it is very clear.

Another important thing in the iron nickel phase diagram is that the gamma phase which is the iron or nickel solid solution is spread or it is basically exist over a large compositional range, alpha is basically stable for small composition range as you see here between 1 to 4 percentage at 600 degrees Celsius temperature, otherwise it is basically gamma is getting stabilized because of iron addition. So, that is for the iron and nickel phase diagram.

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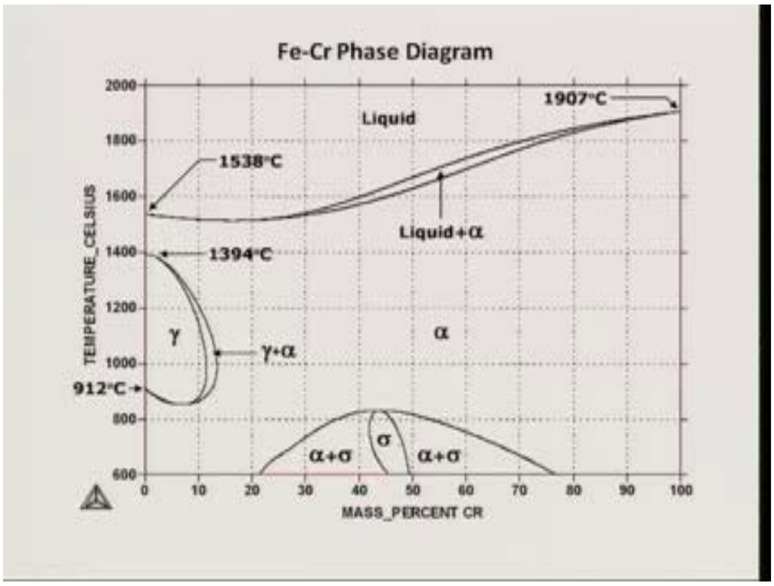

Other than iron chromium phase diagram is you know it is quite a bit different, first of all iron chromium both having BCC crystal structure and because of that solid solution form iron to chromium that is what you see here. It is funny you know isomorphous diagram existing from iron end to chromium end curve chromium melts at much higher temperature and 70 Celsius temperature.

Another important feature is that instead of an iron nickel system, we have seen gamma getting stabilized, but here alpha getting stabilized gamma forming a small loop that is because chromium is basically having a BCC structure that is the space salient features, and last thing which is important is that chromium also very close to very 50 percent chromium. It forms an intermetallic compound known as sigma phase and this is what is shown here. So, alpha basically seems to undergo kinds of the composition forming alpha plus forming sigma alpha plus sigma sigma also correct. So, therefore, the behavior between an iron with nickel and chromium are distinctly different that is what I have seen.

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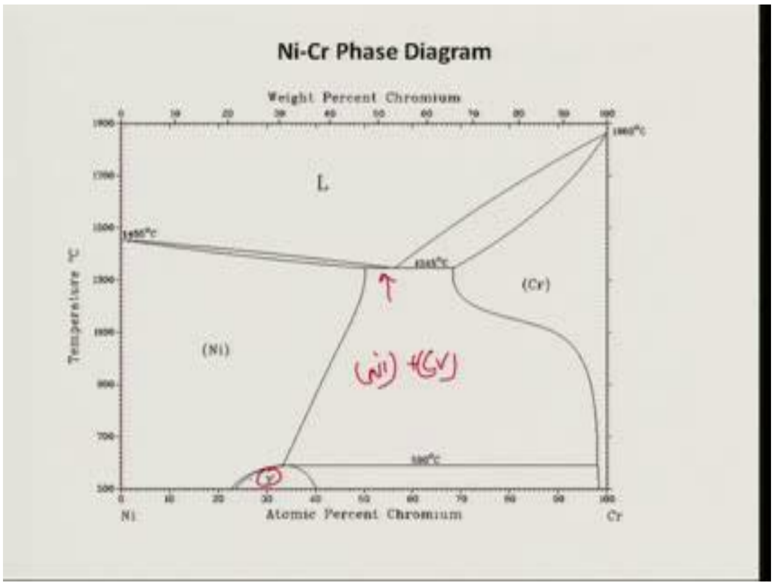

Now, let us do what happens to chromium and nickel; nickel chromium phase diagram is very, very simple as compare iron and iron nickel and iron chromium, why because there is only one eutectic reaction here at 1315 degree Celsius temperature you see here an eutectic is between nickel solid solution and chromium solid solution correct and temperature about less than the 590 degree Celsius temperature.

Some kind of water component gamma prime forms here other than that there is nothing much. So, if I put this thing together we will have a phase diagram which is I have already shown you, but I am going to draw it and discuss with you let me see on the board it was possible let see there. So, basically first I will draw this triangle.

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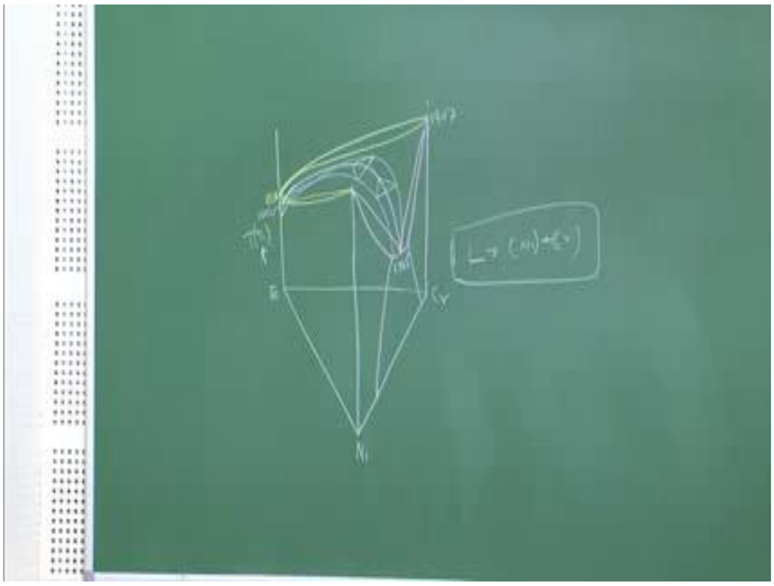

The reason I am drawing this is because all these lectures I tried to show you how to draw these, if you follow my way of drawing then you can draw these things very easily. So, you know that between iron and chromium there is isomorphous phase diagram. So, chromium melts at higher melting temperature as I should draw it with color chalk, otherwise things will be not clear that is between iron and thing iron and chromium lower temperature although it forms a loop, but I am not drawing it here between chromium and nickel you have a eutectic things forming nickel melts at 1556 degree Celsius temperature.

We should increase this little bit, correct and then between iron and nickel, we have a peritectic reaction to the iron end that I have, these are the three binary phase diagrams. So, this is 1556, 1538 and this one is 1907 correct. So, what actually happened if I have these three important phase equilibrium existing at high temperature, what you can do is that we could clearly see that because of presence of these two important reactions; one is very eutectic another one is peritectic reaction the phase equilibrium will be decided by these 2 completely.

So, let me just draw it and show you, how it will be decided by these two, basically nothing, but connecting these two things with this is or let me draw it and so we can actually form a triangle like this. So, basically the three phase equilibria extends this binary eutectic will be extended inside this ternary phase field that is how the phase diagram will looks like. So, as you see here therefore, it depending on the alloy composition temperature ternary alloy either will slide down to this eutectic or the peritectic reaction that is what it is?

So, let me also tell you the temperatures of the eutectic and peritectic reaction. The eutectic reaction takes place at much lower temperature 1345 and peritectic reaction is taking place at high temperature this is 1500-1570. So, that is why the whole equilibrium basically is dictated by this eutectic reaction mostly. So, this is what you should remember the stainless steels actually are in these compounds. So, they lies somewhere there actually. So, they actually when most of these cases undergo peritectic reaction that is what should remember.

But there are different types of stainless steels. A stainless steel contains little bit higher amount of nickel then the peritectic reaction usually happens. In fact, that is why the most of the stainless, the basic problem is the welding. In case of welding, the stainless steel actually undergoes this peritectic reaction and forms lots of cracks. So, otherwise the phase diagram is very simple, but other than that if I take alloys which chromium reaches this side chromium reached. So, they are very easy to handle, but normally it is God does not give the easiest thing in the world. So, that is why actually here the most of the alloys which is stainless steel type, we will be undergoing the peritectic reaction and that is what it is the problem.

So, I guess it is very clear for the binary phase diagrams, what is going to happen. So, equilibrium is basically dictated as I said between it shows a monomer reaction here because it is a binary eutectic and extended to the ternary. So, monomer reaction and monomer reaction curve by reaction monomer and liquid curve distance below the eutectic copper and chromium nickel eutectic isotherm a peritectic reaction of the binary sides and actually, basically if you look at this board the monomeran eutectic, this equilibria which is known or written on the book it basically extend from the peritectic to the eutectics. It is start from peritectic and descend to the eutectic temperature against here that is what is the situation happens other than that nothing much happen in this alloys.

So, now I am giving you some idea about that. Let me just get into the last important phase diagram between silicon dioxide, aluminum oxide and magnesium oxide. So, before doing telling the actual ternary phase diagrams, let me just explain you the binaries if you clearly see here this silicon dioxide aluminum oxide phase diagram.

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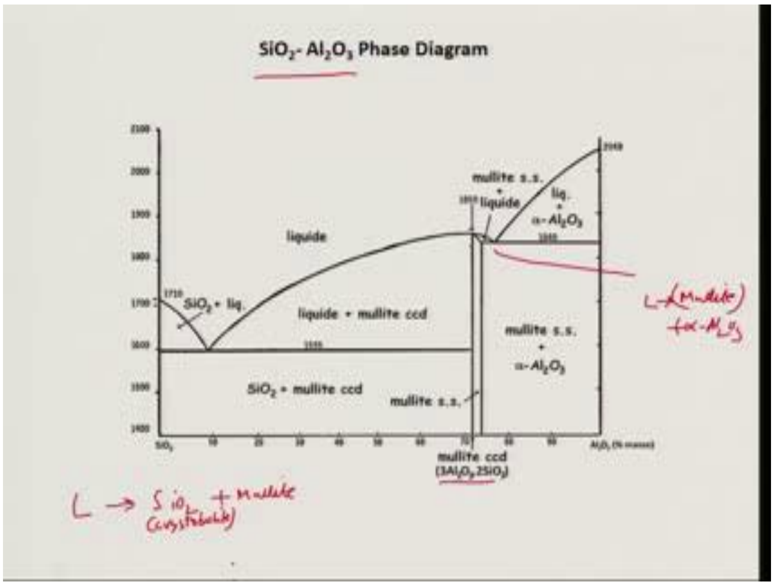

What you have you have you can understand two things. So, one you have a mullite these binary phase diagrams I have already discussed you in the some lectures, you have a intermetallic compound intermetallic compound known as mullite which is nothing, but 3 Al2O3 2 SiO2 compositions and on the both side of that compound there are two eutectic reactions that is the funny part it, but the first eutectic reaction, this eutectic reaction is like this liquid reacting with liquid transforming into SiO2, this SiO2 will be cristobalite you know silicon dioxide existing the co axis of cristobalite different structures at the maximum temperatures plus mullite.

You can see there and then we have another eutectic reaction does this one liquid reacts liquid forms mullite is this mullite solid solutions plus alpha aluminum oxide that is what it is rather than that there is nothing much that means, for the whole phases diagram is divided into two parts, one eutectic between silicon dioxide and mullite, otherwise mullite aluminum dioxide alumina oxide that is all and remember this one this mullite is basically a congruent melting compound which forms at higher temperature..

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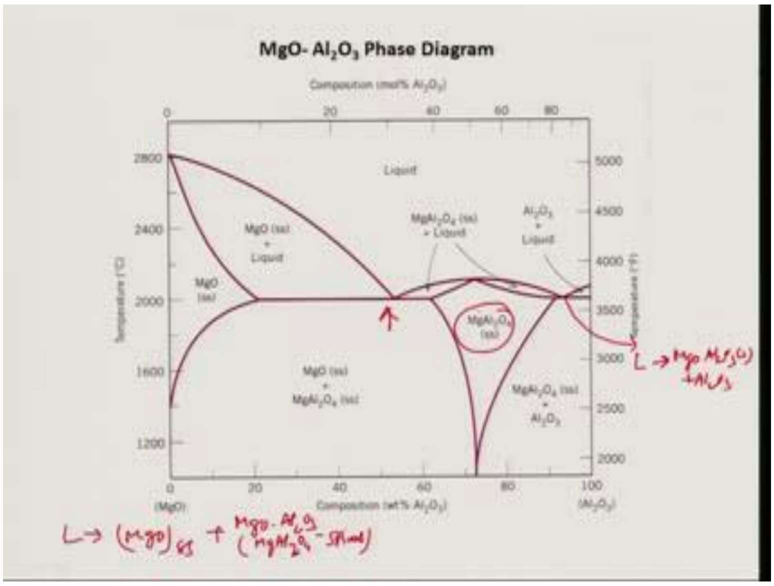

The magnesium oxide, aluminum dioxide minus MgO and Al2O3 phase diagram is also a very simple. They have a two eutectic reaction here also, what are these two eutectic reactions? This is the one eutectic reaction you see here eutectic reaction is like this. It is forms MgO solid solution plus spinel what is spinel MgO Al2O3 many case it is written as MgO Al2O4 or spinel right this is the one and in between you have a spinel formation; that means, the phase diagram between MgO Al2O3 and SiO2 Al2O3 has similarities and this another eutectic reaction which is happens at about at higher temperatures this happens actually about 2000 degree celsius temperature and this reaction is a liquid going to MgO Al2O3 or spinel plus Al2O3 this is spinel actually and in between you have this this compound forms that is about the MgO Al2O3.

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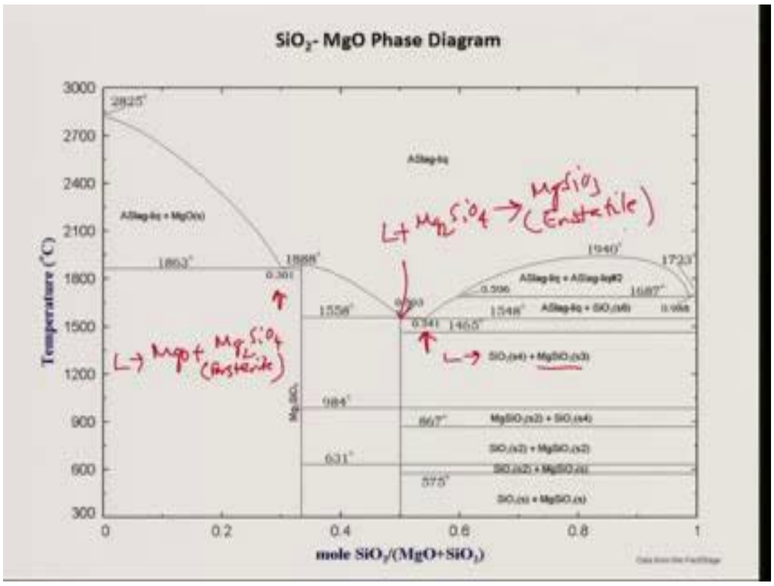

What happens to SiO2 and MgO this is little bit complex, but do not get afraid here you have basically, three reactions on the left side which is the silicon reside sorry, which is the magnesium reside you have basically eutectic reaction, here taking place you see 1888 degree celsius temperature and this eutectic reaction is what liquid going to MgO plus in this solid solution plus something known as forsterite. What is forsterite? Forsterite is Mg2 SiO4. Remember, there are many silicides exists, one of the silicide is olivine other one is forsterite cordierite and this is known as forsterite and then we have a another eutectic reaction taking place on the this side this is the eutectic reaction and is written actually eutectic reaction is between silicon dioxide plus magnesium silicate Mg SiO3 actually.

Therefore, in between there is a eutectic peritectic reaction, here this temperature 1558 as peritectic reaction here actually and this peritectic reaction is like this l liquid plus forsterite forsterite Mg2 SiO4 going to enstatite enstatite is basically Mg2 SiO3 same thing this one this is known as enstatite. So, these are the binary phase equilibrium again I go back if I tell you again. So, in the simple silicon dioxide aluminum dioxide Al2O3 diagram there are two eutectic reactions on both sides of mullite; one is silicon dioxide plus mullite other one is mulllite plus alpha Al2O3 and MgO Al2O3 phase diagram has also two eutectic reaction again it is lying on the both sides of the spinel compound

Mg Al2O4 and one is the liquid going to Mg solid solution plus spinel other one is going to Al2O3 plus spinel the little complex thing is basically this silicon dioxide MgO or silicon dioxide phase diagram we have a eutectic reaction on again on the both sides of the compound called enstatite there are two eutectic reactions one is going to MgO plus MgO SiO4 or forsterite other one is MgO SiO2 plus MgO SiO3 and third one is basically the eutectic reaction the peritectic reaction forming the enstatite or MgO SiO3. Now, if I put these things together, this is what the ternary phase diagram will look like ternary phase diagram is again consisting of there is a separate phase.

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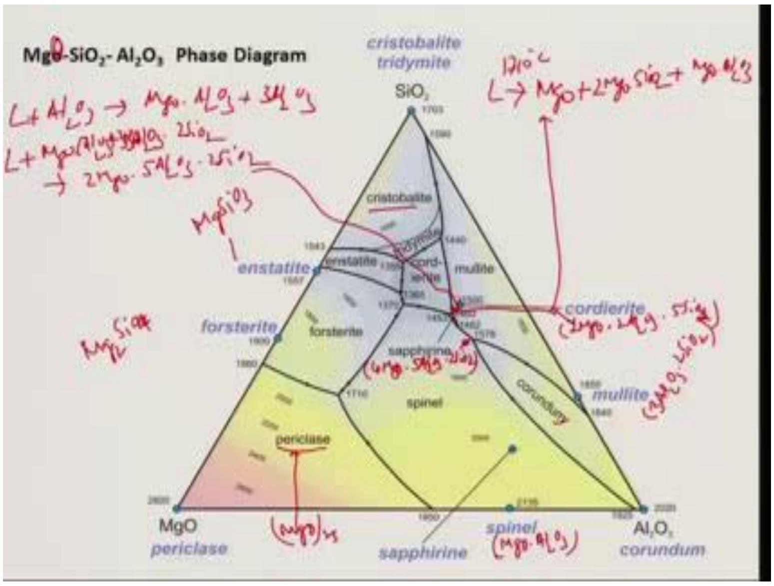

Remember, I will first let me mark it periclase is basically in a binary periclase is what MgO solid solution correct spinel I told you let us first discuss the binary compounds SiO2 MgO. So, between SiO2 and MgO you have forsterite what is forsterite forgotten forsterite is Mg 2 SiO4 correct this is forsterite what is enstatite MgO3 correct along this this side between MgO and Al2O3 you have spinel which is the most important compound which you have seen MgO Al2O3 correct and on the Al2O3 spinel side of the mullite.

What is mullite mullite three Al2O3 two SiO2 correct these are all the binary compounds existing what are the ternary compound existing; obviously, one is periclase periclase is very large solid solution limits of MgO periclase is nothing, but MgO right. In fact, in the literature MgO is always terms as periclase Al2O3 is always termed as corundum alpha

Al2O3 and silicon dioxide can existing cristobalite tridymite state. So, as you see here there are three solid solutions. Let me tell you one is periclase other one is cristobalite third one is corundum spinel actually it is a very stable compound and. In fact, the formalism of spinel is stabilized by MgO additions remember this is basically what do I say this is basically liquidus position of these phase diagram.

So, this is the spinel is very stable. So, you can see here it is stable for large Al2 composition range also it is stable for the large MgO sorry, the SiO2 composition SiO2 addition is actually increase the stability of these silicon spinel. Then you have the forsterite forsterite basically is binary MgO compounds, but addition of aluminum oxide Al2O3 as stabilized a forsterite, you can see the forsterite is getting stabilized here in this part of regions and enstatite is basically stable for small composition region and there are few what do I say few important ternary compound, let me just discuss one is the cordierite what is cordierite cordierite is 2 MgO 2 Al2O3 and 5 SiO2 is the ternary compound and the another one is called sapphirine, sapphirine is basically aluminum silicon compound.

Let me see what is this composition sapphirine shall I write somewhere here yes sapphirine is basically 4 MgO 5 Al2O3 and 2 SiO2 this is the second one tridymite is nothing, but solid solution of silicon dioxide MgO and Al2O3 stabilized at higher temperatures beyond 1700 degree Celsius temperature and that is all actually. So, these are the different phase fields and these are the liquidus surface positions as you see here correct. So, as you know here that this cordierite actually forms by a eutectic correct what is the eutectic reaction basically there are many reactions I show which write down here where actually several reactions 10 reaction.

The first important reaction here is the eutectic reaction this is taking place at higher temperature 1710 degree Celsius temperature it leads to formation of m periclase plus 2 MgO SiO2 this nothing, but Mg SiO3 plus MgO Al2O3 spinel correct this is the ternary eutectic reactions so that means, what these binary eutectic reactions what you see is extended one of the binary eutectic reaction are extended these are the ternary and this happen somewhere here actually these are the two peritectic reactions and this is the eutectic reactions I think this one is what is this one correct then you have some couple of peritectic reaction not of couple of 1, 2, 3, 4, 5, 6 peritectic reactions 6 or 7 peritectic reactions and this 6 peritectic reactions actually are 6 or 7.

Let me see 6 peritectic reactions and this peritectic reactions are very, very interesting I will write down few of them, this is the MgO, this is liquid plus corundum I think this is some are there leading to formation of Al2O3 plus not this one, somewhere else this one is the front this one lead to formation of MgO Al2O3 and Al2O3 is a quadium correct and then the second one is basically liquid plus MgO Al2O3 plus this is a ternary peritectic reaction I am sorry Al2O3 and 2 SiO2 leading the formation of 2 MgO 5 Al2O3 2 SiO2, what is this? This is 2 MgO SiO2 this is the one, this is the cordierite. So, cordierite actually basically form a ternary peritectic reactions, this is the one, this is not this reaction this is this reaction. So, cordierite formation is basically governed by this one which is shown here that is a peritectic reaction.

Now, and then there are many other reaction which I am not going to list it out. So, what you need what you need to understand is that all these equilibria I have just shown you as per this is the peritectic reaction, which is getting task part into the binary ternaries similar this eutectic reactions are also getting extended into the ternaries 1, 2 and 3, 4, 5, 6 eutectic reactions represents. So, there are apply actually there are several more peritectic reactions, which are not listing out those peritectic reaction can lead to formation of sapphire and also some cases string out correct.

But these are all available in the book so, but even you need to detail study in detail. So, what you understand basically from these lectures from these things is that from the binaries to connecting ternaries. It is only way of doing is by extending the binary phase diagrams in the CD space model and that is not allowing, easy in some cases it is direct translation of the binary phase diagrams up to the ternaries like isomorphous systems or 3 phase equilibria what there is a eutectic reaction and 2 isomorphous systems.

But the moment you have 4 phase equilibria existing in a binary, in a ternary system developing then things becomes little bit complex that is what you see here even in these phase diagram also, the stainless steel phase diagram was is very easy because it was only having it is the eutectic and peritectic reaction which are there present on the both the binaries I getting extended there is no ternary true ternary equilibria or reaction taking place inside this Gibbs triangle, but here the ceramic systems you have lot of ternary equilibria taking developing, in fact in these system ternary new equilibria getting developed.

So, that is why actually makes the life little bit difficult, but it is not. So, difficult in the sense that once you know the different various which are forming and because the various formation in these systems are basically compound type that is why probably little gets this make sure. it make our life little bit more difficult, otherwise is hand level. Now, for the next 5 minutes what I am going to say you is that because this is the last lecture the real take care if from these course is basically understanding the binary phase diagrams and to some extend understanding the to some extend getting an idea how the ternary phase diagrams developed.

I would not say that I given you a complete picture of the ternary phase diagrams because that is not possible and that requires lot of understanding of the topology and the space models which is not there in our curriculum unfortunately and. So, when I am trying to teach these ternary phase diagrams even in the IIT, Kanpur also, I had faced the problem that why I am trying to develop this phase models. I always have difficulties to making the students to understanding this phase model, what is inside it that is because they do not have any idea, how the phases will look like in a number. There are many things actually those of you do not know that when in a ternary phase diagram 2 phase reaction and 2 phase zone meeting the single phase zone.

What will be the kind of intersection points is not dictated by these phase diagram specialist is dictated by the lever rule actually lever has discover the rule. Therefore, but they have discovered this rule without understanding the phase diagram, we have discovered we have look at the topology of these phases and then understand the making the developing the rules so that means, what to understand it, you need to go back to understand the topology sapphire mathematical concept, which needs to be first understood then only one can guide into difficult phase diagrams and develop it there is the first thing second thing is that which you probably have taken mean is that all the ternary phase diagrams have full of evaluation. It depends on the binaries; binary equilibria existing peritectic, eutectic, monotectic syntetic whatever they actually isomorphous, they actually gets reflected in the ternary phase model that is, I have tried to discuss in my lectures, in my courses.

So; that means, what that means, that this is the evolution of this ternary phase diagrams is to some extend or rather about 80 to 90 percent actually depend on the binary phase equilibria. So, once you know the binary phase equilibria well, then you can actually understand these the ternary reactions better way. The only things which you need to concentrate if you really need to know the ternary phase diagrams, which is required for ceramics and as well as the multi compound alloy system is that you need to know they ternary phase equilibria, both the ternary eutectic as well as the ternary type 2 and type 3, type 1 is the ternary quasipated in the ternary peritectic reactions. These two actually are needed to be learnt in much better way.

So, for that one is to really read the books and try to draw the pictures and that is what has been told, spins in his book also that if you want to really think in the 3D space phase, if one would think or close your eyes and think in the 3D space phase you need to draw this diagram yourself and then when you are closing your eyes, you can be able to think in the ternary phase space and try to understand, how the phase evolution is taking happening actually in this phase diagrams.

So, that is about the take away other than that I discussed you the binary liquid, solid state transformation, solid to solid transformation in details and these are all very important in many, even colleges I know these diagrams are not dealt with very seriously. They are soothingly done; remember that the metallurgists think in the terms of phase diagrams, equilibrium diagrams and we connect the micro structure of the phase diagrams.

So, in between there is a grey area, what is known as phase transformation. So, my aim is that in the next if I get a time and if I get my chance opportunities, I am going to deliver quick again another course of phase transformations, where these basic gap between the microstructure and the phase diagram will be bridged using the phase transformation concept.

So, once you have this good idea about thermodynamics phase diagrams and the phase transformations also, you will get a good idea about the metallurgical systems and in between one is to lose the diffusion because the phase transformation depends on mostly diffusion. So, therefore, these are the 4 pillars of the metallurgical; physical metallurgy. I would say to some extent, mechanical metallurgy also because phase transformation also, dictates some mechanical wave of material. So, phase thermodynamics and the diffusion are the main pillars and in between lays this phase diagram and phase diagrams phase transformation courses.

So, once you have a good concept of these four courses, we can really go to the different level and make you know; much smooth are in the research or the technological fields of design and engineering material science; material science engineering. Thank you for your presence hearing and these lectures will be available, I guess to you all the students and the different colleges, engineering colleges as well as. So, industry people even after the course are over because that is what NPTEL concept is that to be is, even I have developed another course of an NPTEL forum, which is now available on YouTube; advanced characterization techniques.

Similarly, this lecture will be also available in the YouTube. So, you can see it number of times. If you do not understand something, you can go back and read and look at the basic literature because in the class as there are no question answer sessions. So, I keep on teaching and I do not know how much you can perceive it that is what, is the problem in these kinds of online or video lectures.

In a class room course, you always have interaction with students even there in the teaching also and after the teaching also, but here it is only person after teaching by simply answering few question on the forum, but there is no eye to eye contact in the class. So, that is makes the gap between the student and the teacher much larger and that is probably the problem, but on the same time the Gibb's take away from this course is that, if you have not exposed these course in your colleges to the extent I have turned it, then this is going to give you better understanding of the phase diagrams.

Thank you.