Phase Diagrams in Material Science Engineering
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Lecture – 43
Ternary Phase Diagram-I

Dear students, we are now going to start on a new topic that is ternary phase diagrams. Normally, we are very, very comfortably with binary phase diagrams because they are 2 dimensional plots of temperature versus compositions, but ternary are 3 dimensional plots. So, what we will make you understand how to read these 3 dimensional diagrams, but before that let me just give you an introduction to this ternary phase diagrams.

As you know ternary phase diagrams are very important, why? As I told you the glass which is a very classic material and very useful material is a consisting of minimum 3 components like window glass, they have silicon dioxide, calcium oxide and sodium oxide as a glass. In fact, if you look back history, glass was discovered by the ship long back on the coast of West Indies, while cooking food they were using burning the actually the sand on the beaches of the Caribbean sea and when they are doing it they found that at the end of the cooking something has fused and form a transparent thing and that fusing thing is basically glass and that is how the glass came into the into the history of the human civilization and it is very important.

We need to have glasses transparent things to see across the windows of the car, across the windows of the different other things. So, glass compositions are basically ternary and therefore, we need to understand how this phase forms in ternary phase diagrams.

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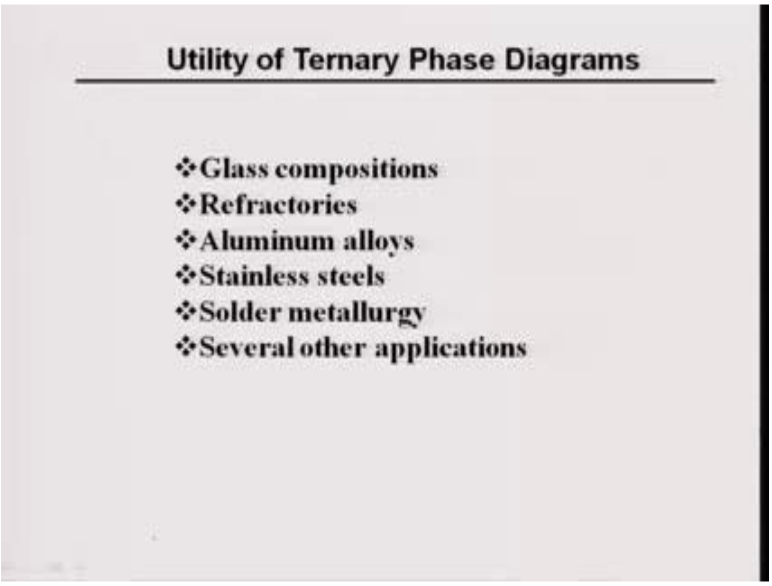

Second important material we use industrially is refractories you know all this furnaces or crucibles. They have a refractory linear, the lining to protect the liquid metal or very high temperature solid from losing heat also to handle the metals very easily. So, the refractories are actually of ternary compo, or the quaternary components refractories are silicon dioxide, magnesium dioxide or they can be other oxide like aluminum oxide or they can be any other oxide, but mostly they are of ternary components ternary 3 components systems.

Then you have many aluminum alloys metallic system like aluminum alloys. Let me just give you aluminum copper silica is a classical alloy, this is the 3 components aluminum cooper and silicon. In fact, we specific aluminum cooper silicon has a ternary eutectic system eutectic between alpha aluminum silicon and l 2 C u basically forms a ternary eutectic and that is one of my favorite subject which I will discuss in the lecture.

So, there are many aluminum alloys there not only aluminum copper, silicon, aluminum nickel you know iron, aluminum copper iron, aluminum copper nickel there are many such systems phases the another important alloy system which is ternary is stainless steel I have already told you that I am going to discuss about stainless steel in ternary phase diagrams. So, stainless steel consisting of iron chromium and nickel as a majority elements. So, carbon is present; obviously, in the steel, but in very low concentration.

So, you know that stainless steel is a actually ternary is system four-fifth, one is a solder material you know, most of the solders are actually ternary or quaternary unlike the solder and you know the solders are actually industrially will be faced out because of the poisons poisonous component like lead and in future it will be completely you know use will be completely restricted. So, we are going to have a new solder alloys and they are mostly you know ternary alloy systems like zinc this one of such alloy system.

Similarly, there are many other applications these are only a tip of the ice berg. I am telling about you there are many other applications where ternary alloy system is used like tungsten carbide nickel, and iron based the system tungsten carbide is the ceramic system ceramic component nickel iron is a metallic component, but 3 together forms a ternary system and this is used in a tungsten carbide cobalt and nickel. So, there are such it is still useful material which forms ternary system, because these are the ternary system ternary alloy systems.

So, it is imperative for us to discuss the phase evolution you know the ternary phase diagram, how to construct them how to read them what are the information we can get out of the phase diagrams this is important that is what I said about 20-25 lectures I am going to spend on this phase diagram itself. 2-3 important books; the first 1 as I told you already is very important by Alan Prince, Alloy phase equilibria.

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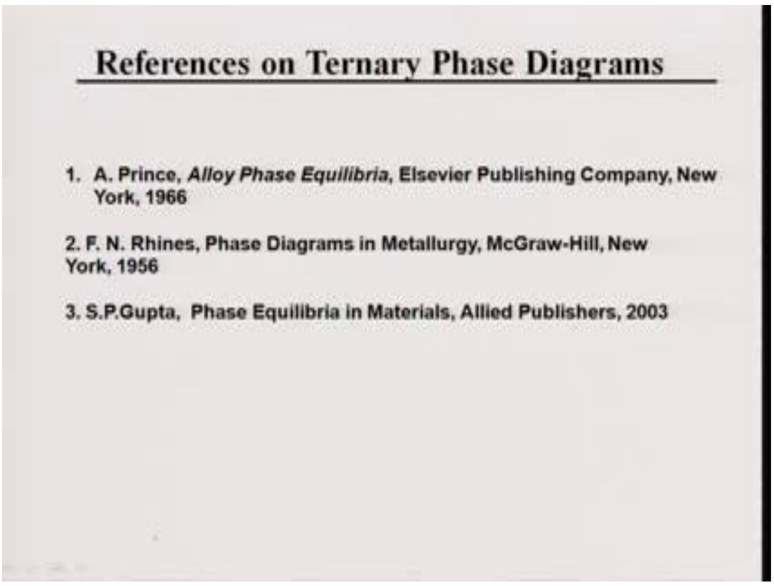

It is Elsevier publishing company it has a large almost half of the book is on ternary phase diagrams then there is a book which is mostly not easily available by Rhines it is on phase diagram in metallurgy, McGraw hills and is also tell you binary phase diagram and the Indian author S. P. Gupta is also from IIT, Kanpur his book is a big one, but easily available cheap is couple of 4 to 500 rupees only it has a large chapter on the ternary phase diagrams. So, 1 can follow any of these books to understand that, why know high what are this ternary phase diagrams.

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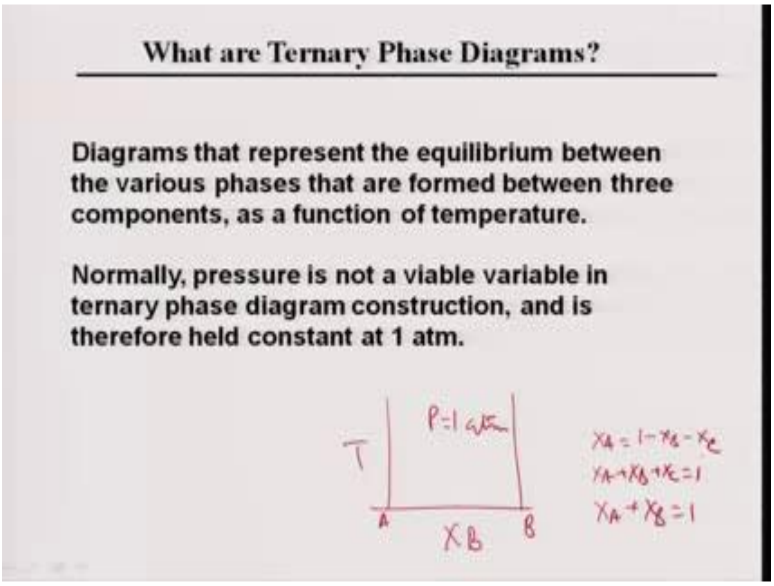

Because I am going to start it from very basic diagrams that represent the equilibrium between various phases that are formed between 3 components as a function of temperature is called it is known as ternary phase diagrams in binaries we have seen what we have seen that binary phase diagram is nothing, but a temperature versus composition why because there are 2 components A and B and if I know 1 of the compositional composition easily known by this relationship where x A and x B has a mole fraction of A and B respectively. So, this is A 2 dimensional plot between temperature and the composition of the other things other composition is obtained does because of the only 1 independent composition variable that is why 2 dimensional plot is enough and we do it at a constant atmospheric pressure 1 at m that is the advantage

Now, in a ternary because there are 3 components A, B, C correct and this relationship do hold A plus x A plus x B plus x C is equal to 1. So, you have 1-2 independent variables and 1 dependent because if I suppose I write x A is equal to 1 minus x B x C right. So, x B x C are known that x A is automatically not. So, there are 2 composition variables x B and x C and temperature variables and pressure is constant. So, therefore, there will be it will be not no longer you can use a 2 dimensional plot we have to go for higher dimensional plots. So, that is the difference. So, ternary phase diagram is a representing of equilibrium of various phases between 3 components.

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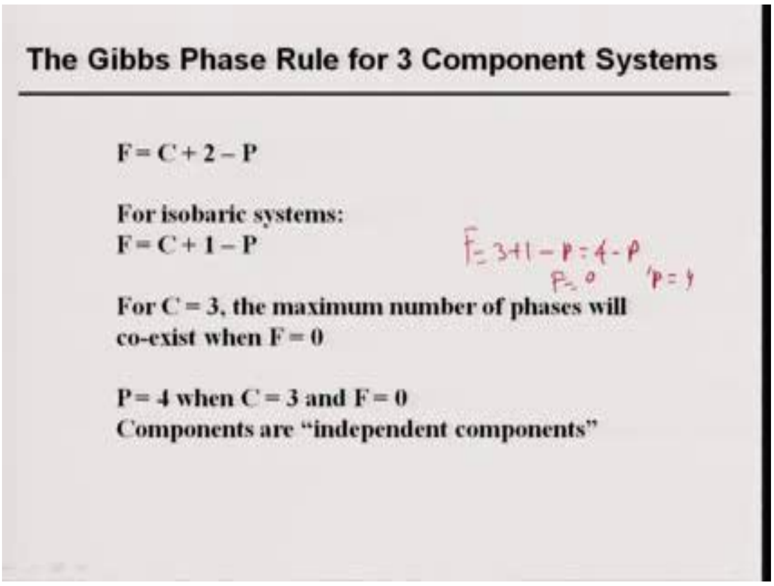

Well, Gibbs phase rule do gets applied here this is basically the fundamental rule as you know F is equal to C minus P plus 2 for a system where pressure and temperature both are not constant both are varying, but due for isobaric system or pressure is 1 atmospheric pressure C you have only 1 that is F is equal to C minus P plus 1 now for a ternary system you have maximum number of component is 3 right because number of component is 3 binary of 2. So, if C is 3 than maximum number of phase will coexists is 4 because F is equal to 3 plus 1 minus P. So, four minus P and minimum value of F is possible is zero therefore, P is equal to 4.

So, therefore, there are actually four phase equilibria possible in binary we have seen 3 phase equilibria right eutectic peritectic monotectic eutectoid monotectoid peritectoid, but here we can have four phases at equilibrium possible. So, that is means what your phase number of phases present in equilibrium is more that is the difference between the binary and ternary well I will look tell you also the moment I talk about binary ternary phase diagrams most of the time I will bring analogy with the binaries.

Therefore, I hope you have understood the binary phase diagrams very thoroughly and then only I mean I will not say then only, but it will your understanding of ternary will be very good the moment you know binary phase diagrams fairly well, but you know this there will be lot of correlation between these two. So, this is the first important application of the text. Now, there are few important atoms to be known before actually I show you a ternary phase diagrams at the end of this lecture.

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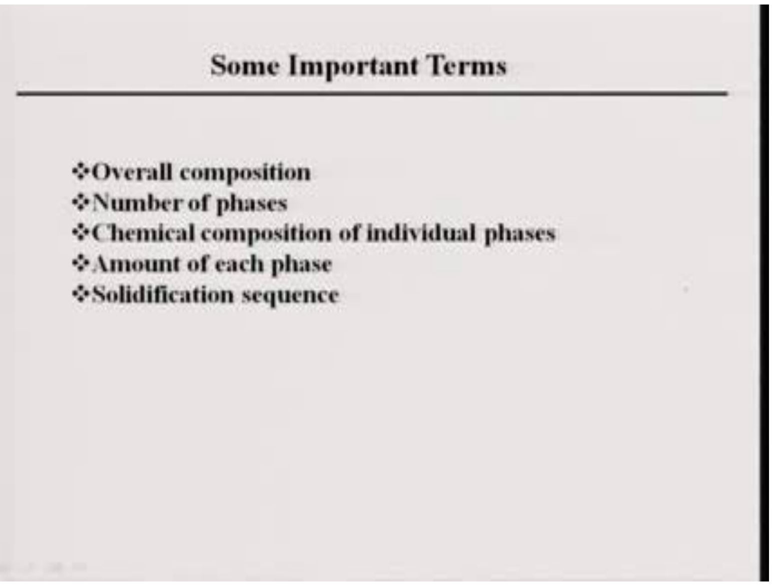

First 1 is the overall compositions number of phase chemical composition of individual phase amount of each phases and solidification sequence. So, these are the things we like to know from the phase diagram or like to read lot of phase diagrams; obviously, solidification sequences is very important that is what we have been doing for all the phase diagrams and here I am not going to do for do anything I will not do actually for solid state transformations, but I will mostly talk about liquid to solid transformations in that in a ternary phase diagrams.

So, you need to know the number of phase present chemical compositions of each phase amount of each phases and solidification sequence. So, you know how do you express the compositions in a binary we express the composition by weight percent atom percent bases or mole fraction bases.

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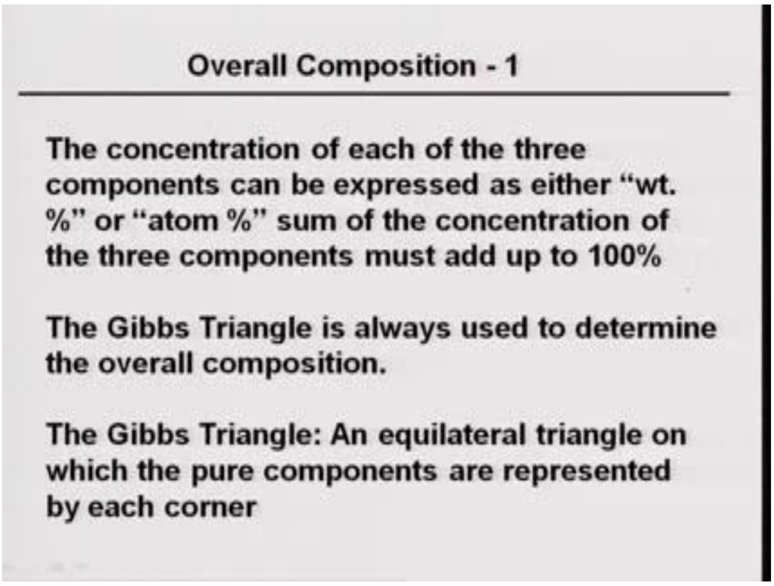

So, the some of the concentrations will be either 100 percent or one if it is presented in terms of weight percentage or atom percentage, then it will be 100 x A plus B plus C will be 100, if it is represented by fraction like x A is equal to fraction x B is equal to fraction x C is equal to fraction then total addition x A plus x B plus x C will be 1 and we use not a line, but a triangle gives isolateral triangles equilateral triangles for composition and this is nothing, but equilateral triangle in which pure components are represented by each corner let me just tell you

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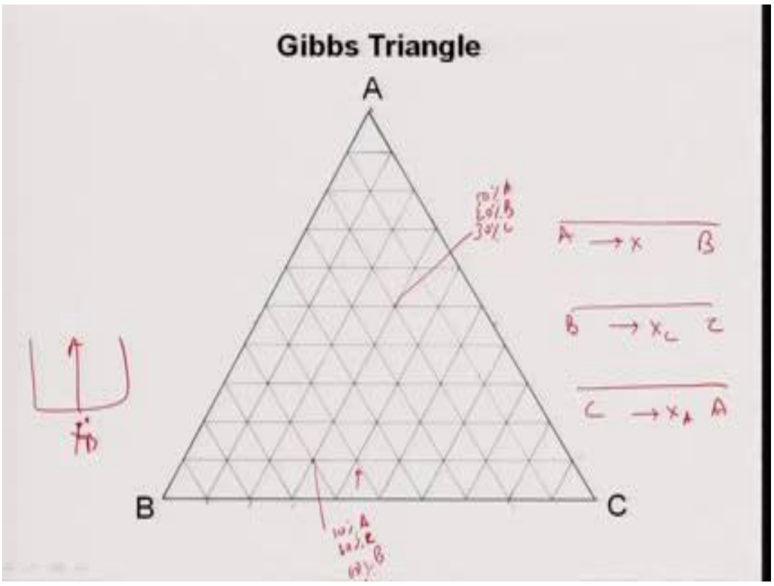

This is what is a compositional represented of ternary phase diagrams as you know there are 3 components A, B and C. So, how to do that for a 2 component system I draw a line right you draw a line A and B or B and C or C and A that is what I do. So, B increases in this direction C increases in this direction A, increases in this direction. Now, what I do I join them these lines and form an equilateral triangle I will explain you why equilateral triangle.

So, if you first try to understand this is the best way of representing the compositions in a ternary system. So, 3 corners are B reach end pure B, end pure C, end pure A, end now on this line from B to A. We already represent binary compositions of A and B tries to understand very clearly on this line from B to A, I we represent compositions of binaries correct. Similarly from B to C different composition of binary B and C, C to A binary C and A, that is the way things is things are done.

So, what will happen each corner tells you 100 percent, B 100 percent, C 100 percent this side tell you A and B mixture, this side tells you B and C mixture, this side tells you C and A mixture. So, any point lying on this will B and C any point lying on this will have no B only C and A, any point lying on this line will have only B and a nothing else try to understand this very carefully. So, thus anything sitting inside the triangle will represent a ternary alloy composition like, suppose this point or this point or this point or this point or this point, they are all the 3 elements. All the 3 components A and B and C represented.

If I want to represent pure A, pure B, pure C I will only go to the corners of the triangle if I represent want to represent A and B suppose A 20 percent B 80 percent then what will happen I will go on a B sides of the triangle similarly B C and similarly C A, but if I want to represent a alloy with a B C or represent like 20 percent, C 40 percent and B 40 percent then I have to go look for a point inside the triangle not on the sides not on the corners I am re writing this fact signal again because this is the mistake students always do and 1 has to understand that.

What is the advantage of that is you know then I can actually divide this triangle like here, I have drawn parallel lines respect to B C 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 that means, what whole height I have divided into 10 lines each 1 is 10 percent 20, 30, 40, 50, 60, 70, 80, 90, 100. Similarly, I divide this way parallel to A B compositions parallel to B C parallel to A C also correct. Now, you know I have done means what I have drawn lines parallel to B C. So, as if I go in the height direction from B C this way if I go this way. So, each of these lines are telling me percentage of a percentage of a 10 percent percentage of a 10, 20 percent 30 percent 40 percent 60 percent 50, 60, 70, 80, 90, 100 because this is 100 percent.

Similarly, if I draw parallel lines with respect to a C I will come to know composition of B 10 percent, B 20 percent, B 30 percent, B 40 percent, 30 percent 50 percent up to I am sorry 10 percent, B 20, B 30 percent 40 percent 50 percent, 100 and same way this way this is 90 percent, 80 percent, 70 percent, 60 percent, 50 percent, 40 percent, 30 percent 20 percent 10 percent and 0 percent because B will have no C. So, you get a cross.

Suppose, this point if I want to know the composition of this point I draw line parallel to A C parallel to B C parallel to C A. So, if you draw parallel to a C I see this contents about 20 percent, 10 percent of A 10 percent of A is it not this is 10 percent line and then if I draw parallel line respect to A B that will tell me C the C will be had must 10 ten 20 30 percent C your 10 percent. This is 10 percent a 30 percent B 30 percent C and B will be how much to get B I have to look at line parallel to A C. So, tell this will be how much you see this is 10 percent B 20, 30, 40, 50, 60, percent B. So, 60 plus 30 plus 10 is 100.

So, I can measure composition or anything, suppose, let me do another point because this is what is very important, suppose I consider this one. So, this point is what this point composition for A I does look at this parallel lines respect to B C; 10, 20, 30, 40, 50. So, is this contains 50 percent a then I look at parallel to A C or I will B composition 10 and 20, you see this is 10 percent, B 20 percent, 20 percent B then I will look at composition lines parallel to A B that will tell me C composition 10, 20, 30. So, you see 50 plus 70 plus 30 is 100.

So, I can actually measure any composition that is the way you should measure compositions because compositions is very important, you have to draw vertical lines at the particular compositions just like a binaries. So, binaries are very easy I draw vertical line this is my x B 0, I know the compositions of the alloy here this is what is now how to measures.

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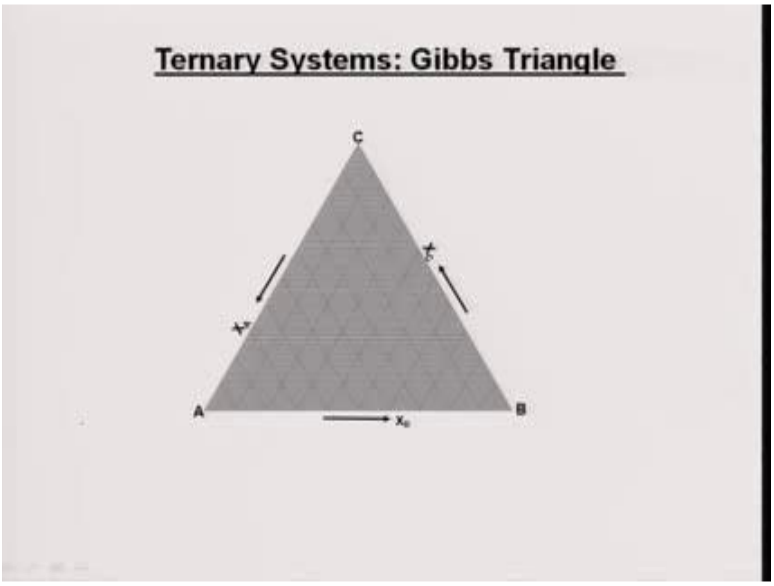

So, in a ternary Gibbs triangle, normally we divide it much, much finer each 1 percentage composition has to be reflected. So, there will be 100 lines parallel to A B parallel to A C parallel to B C and this looks like a clumsy, but anyway you know in the exams you will use such a kinds of to make to put out the compositions to know the solidification pathways to understand various other issues to tell you much easily.

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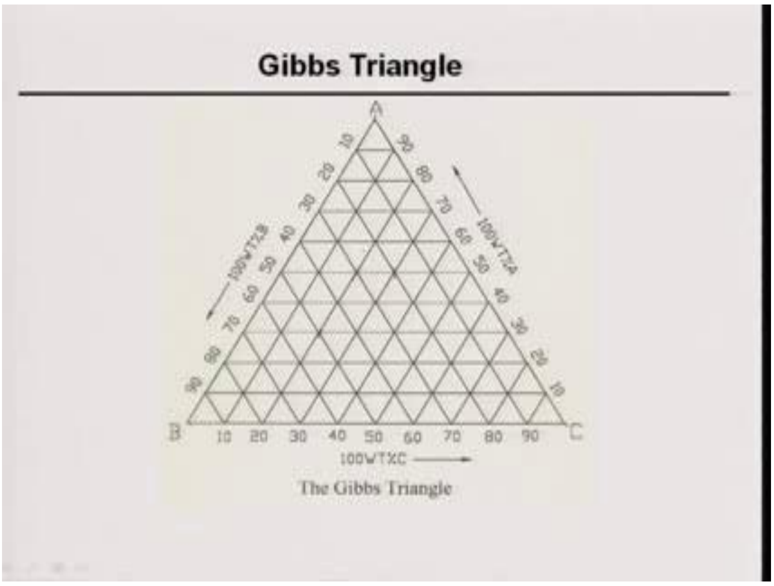

Tlhis is how the things are represented, this is little bit changed I have rotated this triangle this is A this is B this is C 100 percent. So, you can see here C increases this way

10, 20, 30, 40, 50 up to 100 increases this way, 10 to 100 and B increases this way 10 to hundred. So, I can represent any point for composition

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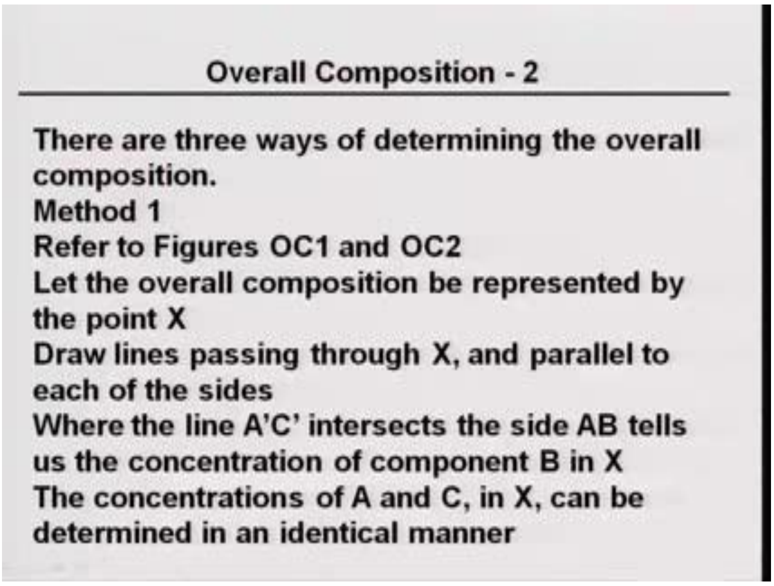

So, there are you know many ways of compositions. Let us not look at it.

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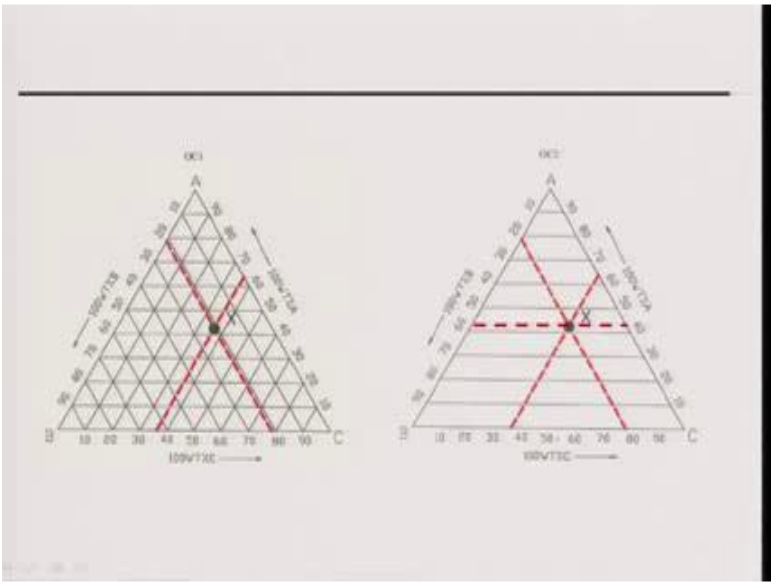

Let us see it here the 1 I told you is this way there is another way of doing. So, see this is the 1 I told you that I draw lines parallel to A B, A C, B C. So, these are the 2 lines we have drawn parallel to 1 is with A B that will tell me C compositions another 1 is parallel to a C which will B compositions. So, if I know C and B I know an automatically I do not need to measure it for the from the Gibb's triangle, other way of doing thing is to put A, you see here that you can actually it you can actually draw normal from this and this shown next time.

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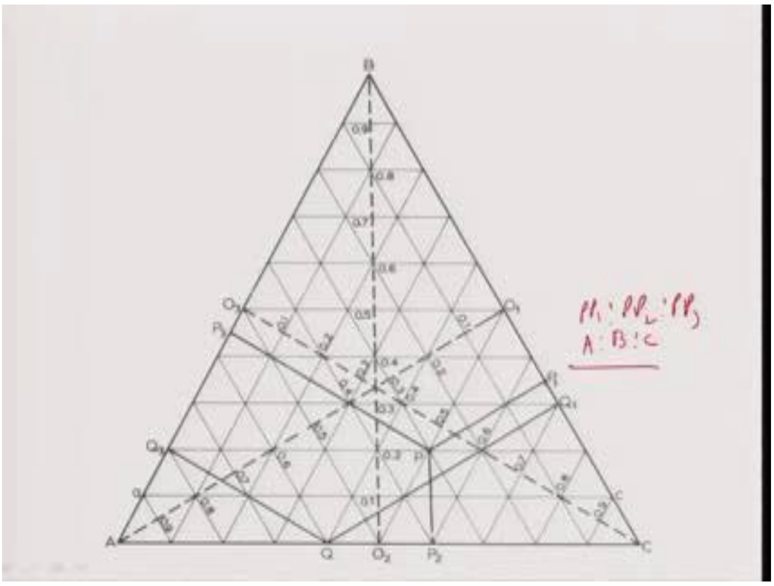

Yes you can actually, suppose this is point P, I know to know compositions. So, I put it normal which you will hit here P 1 which will hit your P 2, P 3 then ratios of these will tell me the compositions P P 1 divided P P 2 divided P P 3. So, P P 1 P is to P P 2 is to P P 3 is P P 1 is you know this is A is to P P 2 will be B is to C that is also possible and this is 1 of the beauty of the isosceles triangle. The isosceles triangles the normal actually will tell you the heights of these points that is the important aspect of this will only happen in equilateral triangle. This will not take place in any other triangle geometrical. So, geometrically this is what this is some actually compositions are done and I told you that how it is to be measured. So, these are all there many ways you can measure compositions and this is another way ratio that is why I told you.

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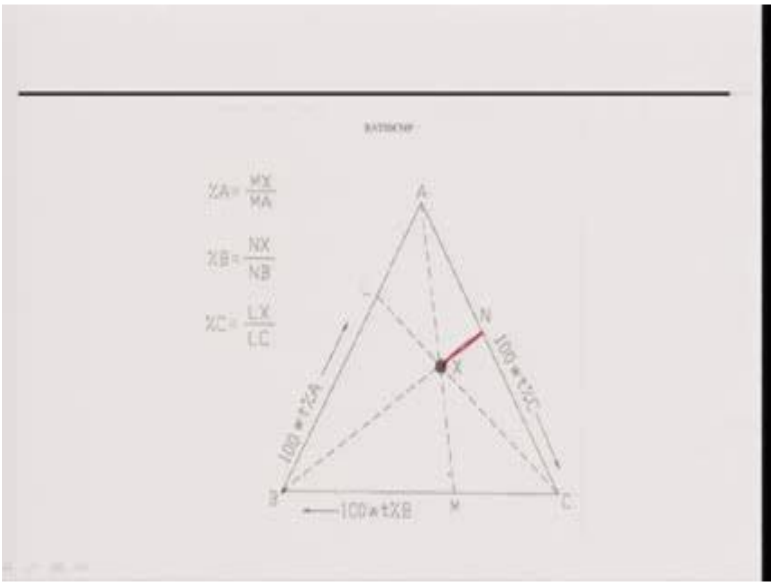

Let us do that suppose I put a point X on inside the triangle and you know I want to know the compositions. So, what I do I just put a normal from X to the A C and extend this to B, this is the normal here and then extended correct. So, compositions of B because this is heating the B end the normal which is dropped from these is mix extended to the B end. So, B will be measured by N X divide by N B correct, you see here this is the N X divide by total N B just like a lever rule.

Similarly, if I want to know A, I have to go to side which does not have any A B C is a side there is no a point a symbol. So, I draw a vertical line which is X M or M X and then I connect it to a pure A end. So, this X M divide by M A, total length of the side is percentage, yes similarly C. So, this is the ratio, there are 2 ways of comp determining; composition 1 is drawing the parallel line respect to A B, A C or B C other one is determining the composition by drawing this, taking the ratios these are the most widely used there are rather ways, but these are the 2 ways, for to measure the compositions.

You can use any of these ways to measure the compositions. So, in the nutshell before I end this lecture as you know measuring compositions in ternary phase diagram is not as simple as a binary. In a binary, you can simply try to get vertical line and X P can be obtained and once you know the X P you can know X C in ternary that is not the way composition represent by equilateral triangle, equilateral triangle will have 3 corners A B, C A will represent 100 percent, A B 100 percent, B C will have different 100 percent

C and the sides will represents A B represent the A B composition B C will represent B C composition C A represent C A composition.

So, each of the sides are actually binaries equivalent to binaries A B, binary B C binary C A binary anything inside the triangle will tell you the ternary compositions and there are 2 ways of measuring ternary compositions; one is by doing parallel lines to this points on which I want to know the compositions, other one is dropping normal to the sides of the triangle from the point for which I want to measure the compositions and using this lever rule to that the 3 ways of measuring, 2 ways of measuring compositions. So, the next class actually I am going to discuss about tie lines, tie triangles and many other steps, but well move very slowly so that you understand the things.