

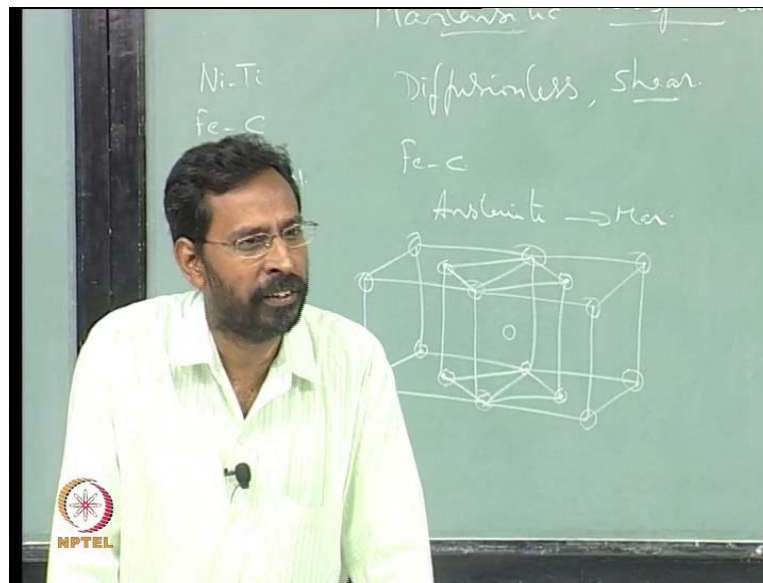
Advanced Metallurgical Thermodynamics
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Module #01
Lecture #26
Martensitic Transformations

Last class we talked about eutectoid transformation; the logical extension of that is the martensitic transformation. Let us look at that today.

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As you all know, this is one such transformation where diffusion is not involved. It is a diffusionless shear transformation. When all diffusional mechanisms fail, that means you come to a temperature where diffusion is not able to happen inside the alloy. At the same time the parent phase is not stable, so it wants to transform to something, but there is no other go, but to go by some mechanism, by which it can transform. That mechanism is a shear mechanism.

You see this happening in many alloy systems. The most classic alloy system is the steels; the iron-carbon alloys. But, you will see not only in that also in the shape memory

alloys if you have heard of. In the shape memory alloys the basic mechanism that gives shape memory effects is the martensite. You see the nickel-titanium (Refer Slide Time: 01:38); people call it as Nitinol and is a very classic example. Iron-Carbon is another example, even in copper, nickel, aluminum, kind of alloys or copper, zinc, aluminum kind of alloys, there are number of copper based alloys where you see. For example, in copper zinc also, you can see martensite formation when you quench it from high temperatures.

All these can be grouped basically into one class of transformation, which we call it as martensitic transformation, where you have diffusionless, shear (Refer Slide Time: 02:16); it is diffusionless transformation and it is a shear transformation. Let us see how much we know and how much this shear takes place? If you look at the iron-carbon example, you see the parent phase that is undergoing the transformation is the austenite. It is the austenite which gives you martensite. In fact, in the last class also we have talked about it.

If in the austenite, the cooling rate is such that the austenite already gives you the pearlite or maybe you have cooled it to a temperature, where you have held it for a long time to get a bainite. Under such conditions, how do you get martensite? We said the only way to get martensite from a bainite or from a pearlite is to take it back to the austenization temperature and see that all the pearlite, all the bainite get transformed to austenite. Then the transformation to martensite is possible. The reason is that it is only one structure transforming to another structure by a shear. Whereas, if you consider pearlite or bainite, they are two phase mixtures, so it is not possible for a two phase mixture to shear, to give you one single phase. Whenever, we are talking about shear transformation, it is one structure where you have a shear along a particular direction taking place to give you a martensite.

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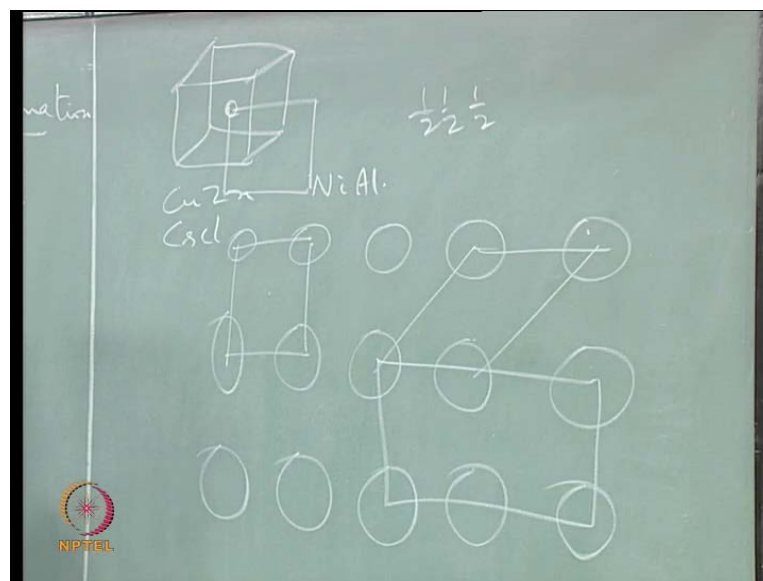
If you look at this, you see in principle and if you start thinking of lattice points here (Refer Slide Time: 04:15) and then extend this, to one more unit cell like this, and look at these two unit cells together, and if the unit cell is a face centered cubic; that means, you have a lattice point here, you have a lattice point here, you have a lattice point here and you have a lattice point here. If I join these lattice points like these two of them and if I

also join these lattice points with the corner atoms or corner lattice points, and join this. In principle what you have generated now? What kind of a structure unit cell is that? It is a tetragonal unit cell and it is not only a simple tetragonal; it is a B C T, because there is one here. The face centered lattice point of this becomes a body centered lattice point for the body centered tetragonal.

You now have a B C T generated out of an FCC. Any FCC unit cell can be thought like this. You do not need a shear there. What is a unit cell? Unit cell is an imaginative way of representing lattice points or the way atoms are arranged. I have atoms arranged in a 3 dimensional structure like this and that I can visualize it as a FCC, and the same FCC can be visualized as a B C T. Why do not we call this cell as B C T? Why should we call it as FCC?

Every FCC unit cell can be thought as B C T unit cell; every FCC cell. Why are we are calling it as FCC? Why cannot we call it as B C T? Have you ever thought about it at the second year B tech level, when people are teaching you unit cells? Is it not? Every FCC can be, simply, I keep on joining. Instead of joining this way and putting all the atoms here or the lattice points there, I join in a different way. (()) You can have continuous; see when I am saying joining two unit cells, there are no unit cells inside a lattice. In a 3 dimensional arrangement of atoms, there is no unit cell. The unit cell that you are imagining that this is a unit cell.

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I give you a simple example; consider a two dimensional unit cell. Imagine all the atoms are at the same size, it is same type of atoms and you have a two dimensional unit cell. Now, the question is I can choose this as a unit cell. I can choose this as a unit cell and I can choose this as a unit cell. So, I have shown you three possibilities. One can imagine in numerous possibilities. Which one should I choose as a unit cell? (()) Symmetry; the smallest unit, which represents the symmetry of the unit cell; you may say that what is the symmetry of it. How do I know? The smallest unit that has the highest symmetry, among those arrangements of lattice points, which has a highest symmetry among those and it should be the smallest.

Now, comes to this. If you look at all this, what is the symmetry of this? What is the symmetry of this? What is the symmetry of this? If you look at it, this has fourfold symmetry. Am I right? This does not have fourfold symmetry. A rhombus cannot have fourfold symmetry. When will you have fourfold symmetry? Can you tell me? In a two dimensional object, when will you get a fourfold symmetry? What is the condition of that geometry which gives you fourfold symmetry? (()) a should be equal to b and the angles should be 90 degrees. So, angle should be 90 degrees and a should be equal to b then only you will get fourfold symmetry. Just because angle is 90 degrees, you need not have to get fourfold symmetry if a is not equal to b. That is what is a rectangle is where a is not equal to b, but the angle is 90 degrees. So, that will give you what kind of symmetry? A rectangle has what kind of symmetry? It is a twofold symmetry. This is what it has (Refer Slide Time: 09:38)

If I now look at this particular unit cell alone; among this and this and if I compare it, it has a twofold symmetry and not only that, the number of lattice points per unit cell, if I consider the number of lattice point per unit cell, then how much is there? For that rectangular unit cell; how many lattice point per unit cell? (Student – teacher interaction: 10:04-10:29) (()) Six; lattice points per unit cell; 2, 3, I am getting all kinds of numbers. Let us see. It is two and why it is two? Corners, (()), one-fourth, wonderful half plus half. Each corner contributes one-fourth, so one-fourth into four, you will get one. This is half and this is half; we are looking at two dimensional lattice. Now, we are not looking at a 3D lattice. So, if you are looking at a 2D lattice, this is it, so it is two, whereas, this is one (Refer Slide Time: 10:45).

In fact, that is the reason why if you have ever seen a face centered tetragonal as there is no face centered tetragonal. Have you ever thought why there is no face centered tetragonal? It is because the moment I have a face centered tetragonal, I can draw the unit cell exactly like this accepting that the c-axis is a little longer and that is it. It is either longer or shorter than a and b and that is what is a tetragonal lattice is. So, it will be exactly like this. Now, I if join this top face center and this top face center with the two corners and **this top face center, this top face center** (Refer Slide Time: 11:24) I mean these bottom face centers with the two corners and join like this, then we will get another unit cell.

That mean in a FCT, I can see a B C T. In every FCT, I can see a B C T. As a result, we cannot say that there is FCT, because FCT can be represented as a B C T and as result FCT does not exist. Otherwise, in principle, if you have ever really broke your head for this problem that there are seven crystal systems. Am I right? And each crystal system can have 4 unit cells, so 28 unit cells should have been there; 28 Bravais lattices should have been there but, how many Bravais lattices we have? We have 14 only. Why only 14? Why not 24 or 28? Its points turn like this; one by one you can take each unit cell and start discarding it with these kinds of arguments. So, FCT is not possible. The FCT is not possible; FCT can be thought as a B C T. Now, the question is why FCC cannot be thought as B C T?

So, if you want remember the basic choice of a unit cell, we just now said that it should have less number of a lattice points; it should be the smallest unit cell with the least number of lattice points per unit cell. It should have the highest symmetry among all possible units that you can think of. In this, this turns out to be that, for this atomic arrangement. For some other atomic arrangement we may have something else. For this particular atomic arrangement where the atoms are equally spaced, and this is equal to this, if that is a case then this is the best unit cell. If this is not equal to this then we may get a different unit cell. That is how orthorhombic comes into picture; the angles may be 90 degrees, but this is not equal to that. So, you would see and you would have a different type of unit cell where a is not equal to b.

So, this is the one and then what else? One more, when we consider the unit cells; I do not know whether you have thought about it. This comes into picture mostly when you have more than one element in the picture. For example, if you have ordered crystal

structure, a simple example is sodium chloride. You have a sodium atom; every sodium atom is surrounded by chlorine atoms and every chlorine atom is surrounded by sodium atoms. Then what is the unit cell if I have considered. I do not consider the composite unit cell which has both sodium and chlorine atoms. I should consider that unit cell where only sodium atoms are considered and another unit cell where only chlorine atoms are considered. It is because a unit cell is always a unit cell of like atoms or of the same type of atoms. That is why whenever we talk about ordered structure we talk about sub lattices and a super lattices. A super lattice is that which is composed of both the elements.

For example, the moment this FCC unit cell or a BCC unit cell, in order to understand easily, imagine a BCC unit cell with one at the center. What is the example of an order BCC unit cell? I mean ordered unit cell based on BCC, **I should not say....** Copper-Zinc, Beta brass, another example is cesium chloride, nickel aluminide, Ni Al; these are all of the type. In that the moment it becomes ordered, I know pretty well that if I am taking a copper-zinc, copper occupies, let say the corners, zinc occupies the body center. Now, what is the unit cell? In the entire unit cells, all the corners atoms are occupied by copper and all the body central atoms are occupied by zinc. I cannot call it any more BCC.

It is no more BCC, because the body centre position is not any copper; again, the body centre position is zinc, whereas body corners are copper. So, we say actually there are two unit cells there. One unit cell is made of copper atoms; another unit cell is made of zinc atoms. What will be the unit cell of copper atom? It is simple cubic cell. What is the unit cell of zinc atoms? It is again a simple cubic. So, you can see two simple cubic unit cells; two simple cubic unit cells and each one displace with respect to each other by a half, half, half. If you think of this unit cell, another unit cell can be drawn like this.

Join all the body centers of eight unit cells, which are surrounding this, you will see that eight body centers when put together, you will get one unit cell. That would be zinc unit cell and zinc unit cell is, if I join or draw the zinc unit cell; zinc unit cell is shifted with respect to the copper unit cell by a half, half, half distance. So, these are two unit cells. One is copper unit cell, another is a zinc unit cell and both are simple cubic unit cells. When put together this one is what we call as the supper lattice. These are the two sub lattices. Copper sub lattices, zinc sub lattices; we need to talk in terms of that. So, that is

why you should never say that copper zinc ordered copper zinc has a BCC structure; it is wrong. It does not have a BCC structure.

In fact, because of this, I now tell you that if you start considering of what we talk sometime back that why ordered structures have low deformability; I said the Burgers vector changes. If I consider this unit cell, the Burgers vector a in a BCC unit cell; what is burgers vector? $1\ 1\ 0$, BCC unit cell; It is half of $1\ 1\ 1$, so that means, this is the burgers vector. This $1\ 1\ 1$ direction is the closest path and now that changes the moment it becomes ordered and it changes to the simple cubic. $1, 1, 0$ or $1, 0, 0$ and it is a full of it. I should not say this; I should say this, because that is the direction; burgers vector is a direction. So, this is bigger than half $1\ 1\ 1$. Am I right? So, the burgers vector becomes longer.

So, you will see suddenly the moment it becomes ordered, the deformation occurs on different planes. Now, it starts searching for different directions where slip can easily occur. As a result, some of the directions; obviously, you will never find a shorter Burgers vector once you are a super lattice. So, as a result you will see the deformation becomes more difficult. You will see many other things. Now, come back to here. What is the reason for why we do not call this as a BCT? Based on whatever we have discussed, why do not we call this as BCT? FCC, why do we not call it as a B C T? It is symmetry; the symmetry of a cubic. What is the symmetry of a cubic system? Did we talk about it? Did somebody talk about it at some stage? What is the symmetry of a cubic system? In fact, you always might have learnt in cubic is that a is equal to b equal to c ; α equal to β equal to γ equal to 90 degrees. It is a very primitive way of learning, I would say.

The best way to know about crystal systems is to know the symmetry of it. In fact, then you will know when you say cubic, tetragonal, orthorhombic. Why do we actually learn them in that order? It is because symmetry decreases in that order. Cubic has the highest symmetry, triclinic has the lowest symmetry. That is why we talk about triclinic at the end and that is why you do not see most of the elements actually occupying a triclinic system. Every element, almost tries to have as close packed structure as possible as long as its electronic configuration allows it. That is why you see if you see the whole periodic table, out of some 105 elements or so, at least 80 elements or 80 to 85 elements fall into cubic or hexagonal. It could be FCC or BCC and hexagonal.

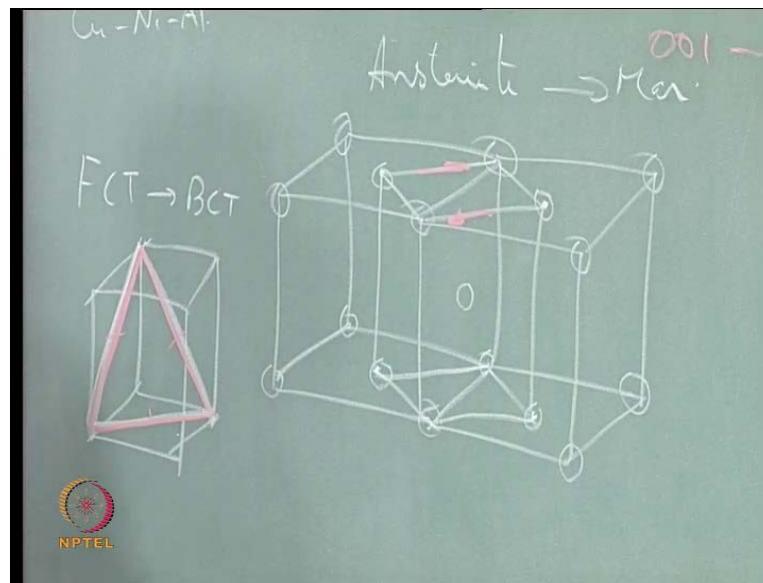
So, you see these are the three, which are the most popular. It is basically, because they are the most close packed; I mean not just due to close packed, they are the most symmetric. So, if you look at cubic, what is the symmetry of cubic? It is threefold; how many three folds? It has four three folds. Where are these four three folds? At diagonals, body diagonals, you have eight corners. Join any two opposite corners of the eight corners; join any two opposite corners out of the eight corners, then you get a direction, which is a $1\ 1\ 1$ direction and that $1\ 1\ 1$ direction is a threefold direction and because there are eight corners, so four such $1\ 1\ 1$ directions are possible.

In fact, actually how many $1\ 1\ 1$ directions are there of total? Total eight are there, eight $1\ 1\ 1$. In fact, there are eight $1\ 1\ 1$ plains and that is why we call it has an octahedral plain. $1\ 1\ 1$ plains are called as octahedral plains and the reason is because they have eight of them, but we are only considering four here because if I consider $1\ 1\ 1$ and $\bar{1}\ \bar{1}\ \bar{1}$; they are exactly the same except that they are in the reverse direction.

One is in this direction another is in this direction. So, both fall on each other except that the directions are different. So, they can be considered as one axis only. So, out of the eight you will see 4 pairs like that. If I take one $\bar{1}\ \bar{1}\ \bar{1}$ and it will be parallel to what? $\bar{1}\ \bar{1}\ \bar{1}$ will be parallel to? This will be parallel to $1\ \bar{1}\ \bar{1}$; it will be parallel to $1\ \bar{1}\ \bar{1}$. Similarly, we can see this and this and this will be considered as together; these two directions. There will be basically same direction opposite to each other. So, like that you will see four sets and that is why we call them.

In addition to four threefold axis, what else you have? Any cubic is there? There is another important symmetry is there. Three fourfolds you have; you have three fourfolds. You see every face is a square; every face is a square in a cubic. So, as a result this direction, this direction and this direction; the $x\ y\ z$, all the three directions are fourfold axis in a cubic. So, you have three fourfold axis and four threefold axis. This is the highest symmetry that any crystal can have. That is why the moment you take cube and then pull it then what happens to the cube? It becomes tetragonal. Once it becomes tetragonal, what happens to the crystal symmetry? The threefold disappears; threefold completely disappears and the reason is that for the threefold to have, if I consider this plain; I will draw this maybe here. We can show it here; I will not show there.

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If I consider this plain then this is your 1 1 1 plain. The 1 1 1 plain is the one, which has the threefold symmetry. What is the shape of that plain? A triangle and a triangle will have threefold symmetry is when all the three sides are equal; when it is equilateral triangle. If it is not an equilateral triangle then you will not have threefold symmetry. In a cube, you have a 1 1 1 plain and is an equilateral triangle. In a tetragonal, 1 1 1 plain is not a equilateral triangle, because you have pulled it, so this and this will be longer than this in a tetragonal and because of which you do not have an equilateral triangle.

Once you do not have an equilateral triangle then there is no threefold symmetry. So, all the 1 1 1 plains have completely got converted into equilateral triangles now, I mean non equilateral triangles; isosceles triangles. They are all isosceles triangles and once they are isosceles triangles; obviously, you do not have a threefold. So, you do not have threefold symmetry at all, the four threefold that we talked about in a cube. Just by pulling it by few percent, you have changed it completely, you have vanished it, I mean you have destroyed the threefold symmetry. Then what about fourfold symmetry? Only the top and bottom faces are squares now. The remaining four faces are no more squares because you have pulled it. The remaining four faces, what they have become? They have become rectangles and rectangle cannot have fourfold symmetry.

So, only the 0 0 1 direction, which is a c axis, that alone will have a fourfold symmetry, and 1 0 0 and 0 1 0, these two will not have a fourfold symmetry. Whereas in a cubic

both $1\ 0\ 0$ and $0\ 1\ 0$ and $0\ 0\ 1$, all the three of them have fourfold symmetry. Here, you will have only one fourfold symmetry. You see from cubic to tetragonal what degradation in terms of symmetry. You simply have one fourfold symmetry and that is it. You may say that it also has a twofold symmetry, because rectangles are there. Since, two twofold symmetries are there, then why am I not talking about them? It is not contained inside.

The two twofold axis like, the $1\ 0\ 0$ is a twofold, $0\ 1\ 0$ is a twofold, but $0\ 0\ 1$ is a fourfold. Why are these two contained in this? They are not contained in this. These two are in two different directions, which are at 90 degrees to this direction. They are not contained then why do we not talk about it. We do not talk about it, because whenever we talk about symmetry of a unit cell, we talk about what is the highest possible symmetry of that unit cell. Because, fourfold is possible, we do not talk about twofold though twofold does exist inside the lattice; fourfold is possible and that is why in cubic also, we say three fourfolds, we do not actually talk about four threefold are as a result of three fourfolds, because, a is equal to b equal to c and all the angles are 90 degrees, the three fold is also coming in the way.

So, you can see that it has one fourfold and now from there if you go to orthorhombic you will see then again there is a further degradation. There is no more fourfold at all in orthorhombic. Why there is no fourfold? All the six faces are rectangles. Why it is because a is not equal to b not equal to c . So, there is no fourfold, but all the angles are 90 degrees. Here, α is equal to β equal to γ equal to 90 degrees, because all the angles are 90 degrees, you have rectangles. If there is no 90 degrees then you would not even get rectangles. And because you have got rectangles, you have some symmetry. What is that symmetry? In a rectangle, you have a twofold symmetry and so what is the symmetry of an orthorhombic? It is not twofold; it is three twofolds, like the way we said for cubic there are three fourfolds, here there are three twofolds.

Three mutually perpendicular twofolds; a , b , c , all the three are twofolds, because all of them are rectangles. So, like that you would see from one to other if you start going from orthorhombic you go to rhombohedral. How do you get rhombohedral structure? You get it from a cubic structure. If somebody gives to you cube and ask you to pull along the diagonal and once you pull along the diagonal. What happens now? All the directions, all the sides may remain equal, but angles will not be any more 90 degrees. Once the angles

do not remain 90 degrees, you cannot have a twofold symmetry and you cannot have fourfold symmetry.

So, there is no twofold, no fourfold in a rhombohedral, because their angles are not 90 degrees. For example, if you have this kind of a structure there is no twofold here. (Refer Slide Time: 31:14). This is like a rhombus; rhombohedron is almost an extension of this rhombus in 3D and this cannot have a twofold symmetry, because this angle is not 90. What is the meaning of a twofold symmetry? When I rotate a particular lattice point around another lattice point by 180 degrees then if I do come back to another lattice point inside then that is a twofold symmetry.

So, that is possible only when the angles are 90 degrees. So, you will not be able to get that. So, once you do not get that then obviously, you have no twofold, no fourfold, but you have one threefold symmetry in rhombohedral. You can geometrically prove it there is one threefold symmetry. Similarly, when you go to a hexagonal, you have six-fold symmetry there, because the basal plane has six-fold symmetry and at the same time the rectangular planes, which are surrounding the basal planes. I mean the top and bottom basal planes are connected by six rectangles.

So, those rectangular planes also will have a two fold symmetry, but we do not talk about that. We say that hexagonal has a six-fold symmetry, because twofold symmetry is much less than a six fold symmetry. Though we say six fold symmetry is higher symmetry than a four fold symmetry, we do not put it above cubic, because cubic has three fourfold symmetries, whereas, here only one of the axis has higher symmetry than fourfold. The remaining axis have a lower symmetry than the cubic and that is why cubic is always above the hexagonal in terms of symmetry.

So, whenever certain elements want to choose a structure, the first structure it would like to choose is cubic and if that is not possible then it will choose something else. So, that is how it is then you go to monoclinic. In monoclinic, you have one 90 degrees angle. If you remember, a is not equal to b not equal to c , β is 90 degrees and the remaining two are not 90 degrees. So, because there is one 90 degrees angle, you will get one twofold symmetry. So, monoclinic has one twofold and then you come to triclinic. What is the symmetry? Zero symmetry or one fold symmetry; it has one fold symmetry. There

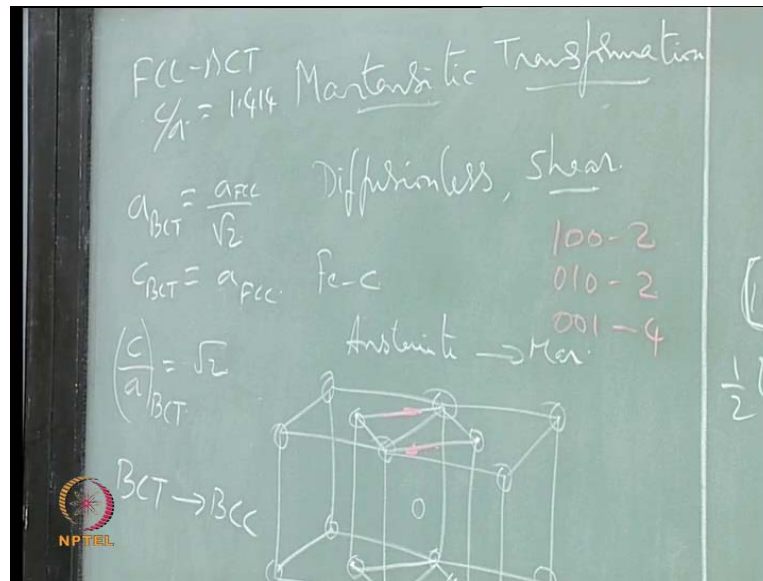
is nothing like has zero symmetry. Every one of us has one fold symmetry; you rotate around yourself, 360 degrees, you will be able to generate your own self once again.

Every object has to **have a three fold** have one fold symmetry. One fold symmetry is what we call it has trivial symmetry; it is a symmetry, which is supposed to be there everywhere, because it is a 360 degree rotation. Any object, when you rotate it by 360 degrees comes back to itself. So, coming back here, sorry for all these deviation, coming back here, we say it is not B C T, because in cubic, the same arrangement I can also think of as FCC. FCC has a higher symmetry than a B C T. So, I will consider these atomic arrangements as FCC rather than a B C T; same atomic arrangements, I can also when there is choice between two unit cells possible. I will choose that particular unit cell, which has a highest symmetry because that is one of the criteria to choose a unit cells.

So, that is why it is called a FCC. Now, when there is a shear that takes place, the shear actually occurs along the 1 1 0 (Refer Slide Time: 35:19), which is a closed pack plane, in closed pack direction. So, along that direction you have a shear and once the shear takes place the FCC permanently becomes a B C T. Because once the shear has taken place, it is no more FCC; it has become B C T, because of the shear; not just because of the atomic arrangements, because of the shear that is taking place along that. If the shear would have taken by any other plane or in any other direction, you would have got some other structure possibly, but because it occurs on the closest pack, in the closest pack direction, atoms are close pack there, you would see that it becomes B C T.

Once it becomes; that is F C C becomes B C T, what is the c by a ratio? 1.414, perfect and you can see the c now is same as a, c of the B C T is equal to a of the F C C. Nothing is happening to this. Only thing is now a and b of the B C T are these two. Those two when you compare with the original FCC structure, what are they? They are half of the face diagonal, face diagonal is $\sqrt{2} a$ by 2 so; that means, a boy $\sqrt{2}$.

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So, a of the B C T is equal to root 2... I am sorry, not able to write here, I will write somewhere else. So, a of B C T is equal to a by root 2 of FCC and c of B C T is equal to a of FCC. So, if I take c by a ratio it becomes this divided by that and that is equal to root 2. So, c by a of the B C T is this. After the shear, if I look at the c by a of the B C T, it is actually root 2, but such a structure, BCC structure with a c by a of 1 by 1.414, it is not stable at room temperature, because in the phase diagram, I do not see such a structure.

So, what happens in the system that is stable at the temperature in the phase diagram is a BCC structure. At room temperature, in an iron carbon system what is stable is a BCC structure; B C T is not stable. So, what happens is this particular structure wants to transform to a BCC structure. That is why the whole martensite transformation is composed of two processes; one is a shear, which converts the FCC into a B C T, then another process whereby this B C T wants to get converted to BCC. What is that can convert a B C T into a BCC? If you want a B C T to become BCC, what should happen? Forget about carbon, we are talking of only structure; c axis has to shrink and a and b have to elongate, so that the c by a, becomes one. If c can shrink completely without a and b elongating, I have no problem. Ultimately, I want the c should become equal to a.

That means this has to shrink and this has to elongate. These two have to elongate and this has to shrink and that is where the whole problem is in a iron carbon diagram. In iron carbon steels, if you now look at this whole structure and see where carbon atoms are

sitting, you will see very interesting phenomenon. Carbon atoms in FCC sit at the octahedral sites. Let us look at the octahedral sites. One of the most common octahedral site in a FCC is what? It is a body central position.

Body centered position is an octahedral site. In this, the body centered position is this. (Refer Slide Time: 40:53) The body centered positions of the FCC are these two and that is where the carbon atom will sit. What are the other octahedral positions? Edge centers; so that means, this is a edge center and this is also an edge centre. This is also an edge centre and this is also an edge centre.

I am not considering other points, I am only considering that corresponding to the B C T, so that means, once the shear has happened, carbon atoms have not moved anywhere, they are where they are. That is the meaning of martensitic transformation. If the carbon atoms can move then why will shear occur; martensite would have not found. It would have found bainite; if carbon atoms could have moved it would have formed a bainite. Because carbon atoms are not moving and they are where they are exactly, they will remain, once the FCC becomes B C T, the carbon atoms are actually sitting here.

These are the four edge centers; I mean these two body centers, if you want I will differentiate body centers from the edge centers. These are the two body centers and the remaining four that I have put are the edge centers. Now, if you look at it, out of the 6 positions of the carbon atoms, are there any other positions possible for the carbon atom in this particular unit cell? No, that is it, those are the edge centers and those are the body centers. Once, you consider that out of all these six positions, four of them are at c by 2 positions of the B C T. They are at the center of the c axis, the four of them, and because carbon is sitting at the center of the c axis; for the c to shrink are not easy; c cannot shrink now, because carbon is sitting there; it cannot shrink and because it cannot shrink, then B C T cannot become a B C C.

That is why whenever you look at a martensitic transformation, in fact, if you carefully observe a typical martensite like a 0.8 percent carbon steel martensite, what the c by a ratio in that martensite is? No, it not 1.6. The maximum possible is this (Refer Slide Time: 43:24). When a FCC shears, this is what is the maximum. You cannot have beyond that and the actual martensite will not have that. Go back to any of your physical metallurgy books, look at the c by a ratio, and we always say c by a ratio increases with

increase in carbon content; if you remember c/a of martensite will increase with increase in carbon content. Why it is because the more and more carbon content the probability of these places occupied by carbon is going to be more and more.

So, there is more and more difficulty in the shrinking to occur for the c axis and that is the reason why c/a ratio does not decrease. Usually, c/a ratio is in the range of 1.1 to 1.2 or something like that or 1.05 also people observe, depending on what is the carbon content. So, some shrinkage will occur, but not all. As a result this will not come to one. When will this come to one, when carbon is not there and that is why any of the iron based alloys where carbon is not there then you can have a martensite, which is a BCC martensite. It will be a soft martensite. All martensites need not be hard; BCT martensite is hard because of its structure and because of the strains associated with the shear. There is a strain associated with the shear even in BCC and that alone will give you an additional strengthening, but otherwise as such it is a BCC.

It is martensite because it formed by shear and that is it. What exactly causes is because the atoms are not able to move. The atoms are not able to diffuse and FCC is not stable at the temperature. So, it wants to finally, come to an equilibrium shape or equilibrium structure, which is a BCC structure. It can come as a normal pure iron, when you take a pure iron at high temperature, above 910 degrees Celsius, it is FCC, below 910, and it is BCC. How does this FCC to BCC transformation take place when I am cooling up above 910 to below 910? How does the transformation occur? It is by short range diffusion. The atoms, which are sitting at the body centered face centered positions move to the body centered positions and as a result you generate a BCC structure. From every one FCC unit cell you generate two BCC unit cells. There are obviously there.

There are four atoms, four lattice points per unit cell. Here, you have only two lattice points per unit cell. So, by this kind of atomic rearrangements in a short range, which is of the order of one unit cell dimension movement of atoms; atoms do not move beyond that and that is what is a short range is. But, the same FCC and if I quench it to room temperature, the same pure iron; FCC gamma iron, If I quench it to the room temperature, then this iron wants to become BCC, because FCC is not stable at room temperature. It now forms a BCC by a shear; it first forms does a shear then it gets converted to BCT and this BCT, because there is no carbon atoms, because of BCC is the stable structure, not the BCT, it transforms to a BCC.

So, ultimately is a structure is BCC, but this BCC has been got by a shear process that is why this BCC will be stronger than the original BCC, which has been obtained by a normal cooling. So, by quenching FCC pure iron, you would get a strengthening that martensite will be stronger than the original BCC iron. But, it would not be as strong as a B C T martensite in the steels. So, this is how you would see.

For example, if I take iron nickel alloys; in iron nickel alloys also you see the same type of transition taking place. No, in our iron carbon diagram what is the low temperature state? Do you remember the phase diagram? There is nothing like FCC is a stable state; it depends on which particular electronic configuration of that element. For example, there are metals which are forming B C T. Is it not? There are so many, like tin is a B C T structure; it is not even a cubic structure. So, different elements get different crystal structures depending on what their electronic configuration, which allows it to have. If it allows it to have FCC, then yes. We say that cubic is the most popular; among the cubic some can be F C C some can be BCC.

One thing I want to tell you that in FCC and BCC, the symmetry is the same; whenever we talk of symmetry we do not talk of symmetry of a unit cell, we talk of symmetry of a crystal system. (No audio between: 48:47-48:59). If you look at the entropy, it is just based on loose packing. I do not think that is the right way of looking at it. Yes, you can say that because it is loosely packed, the heat capacity will be higher and could be higher. Only that much I can say, because atoms can vibrate more easily (()), it need not, it will also result to higher enthalpy. Enthalpy is also integral $c_p dt$. So, it is not like that. To the some extent it is more open space, but the thing is not that more open space does not mean more disorder. It is not? It does not mean that you cannot say BCC is more disordered than FCC; you cannot say that.

It is as ordered as an FCC is in terms of in atomic ordering. (()) Yes it is like for example, liquid that is where the problem is. In principle, that is why FCC again becomes BCC at higher temperature; FCC again becomes BCC. It is magnetic transitions that are there in iron, which make this happen. FCC to, I mean BCC to FCC and F C C again going to BCC. But there are structures where you would see for example, if you take cobalt; cobalt is H C P at room temperature and becomes FCC at high temperature, but there are also examples where the H C P at low temperature becomes a BCC at high temperature; titanium is such an example.

But there are also examples where it remains H C P up to the melting point; magnesium, zinc is H C P up to melting point. So, these structural transitions are more fundamental issues. You need to look at what actual issues related to whether this material is magnetic or not. That again influences to certain extent whether... (()) ferromagnetic remaining is not. But in all these three, if you take nickel, it is FCC up to melting point; iron has a BCC to F C C to again BCC, cobalt you take it is H C P to F C C. So, all the three and though the three of them are ferromagnetic they do not have the same type of structures.

That means, it is again because their electronic configurations are different. (()) It could be, I mean 1 1 electron can make copper and zinc, you see they are entirely different; it also 1 1 electron, they are entirely different. So, it is more fundamental issue. We need to understand. I do not think physicists also have understood this that well, still they do not know. I at least do not know still. (()) no, lattice positions do not because that is what we say shear. So, shear basically means the one lattice structure changes to another lattice structure by a shear that is it and once that happens that wherever lattice positions are there, this is what we call it has bainite distortion.

We will stop now.