An Introduction to Materials: Nature and properties (Part 1: Structure of Materials)

Prof. Ashish Garg
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture – 08
Symmetry in Crystals (contd.)

So, we now start again a new lecture. So, let me just. So, we are at the end of Rotational symmetry. So, we looked at Translational symmetry, which is from going from one, translating from one lattice point to another, which is present in crystals. Second was a mirror symmetry, the example of mirror symmetry can also be present in 3-D or 2-D. So, here again you can see that, you can have a mirror plane for example, you can see in this case.

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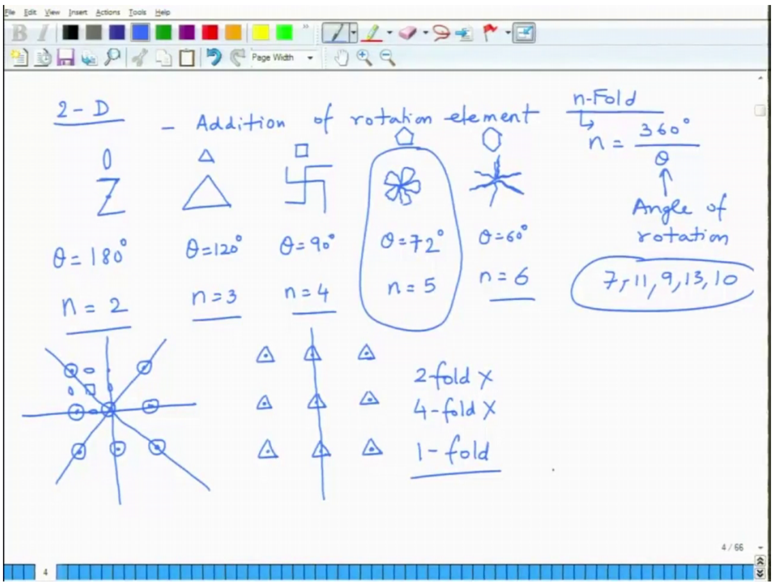

You can have a mirror like this, you can have a mirror like this, you can have a mirror like that, you can have a mirror like this. So, there are so. In fact, let me just basically have a mirror like this, horizontal mirror, vertical mirror, diagonal mirrors ok, but in this case, you can see on the right, you do not have a mirror plane there right. So, you can have your sorry you have a mirror plane like this. If you come in a plane you have not been a plane, but you can see the number of options of mirror plane have reduced. You have a mirror plane, but you do not have all the mirror planes as you see on the left.

Similarly, rotational symmetry options have reduced because of motif. So, what I wanted to emphasize it at that point was, it is not merely the apparent shape that looks to you is important; it is the consideration of these criteria, whether it has rotational symmetry, whether it has mirror symmetry, these are important in defining a particular type of lattice sort of shape.

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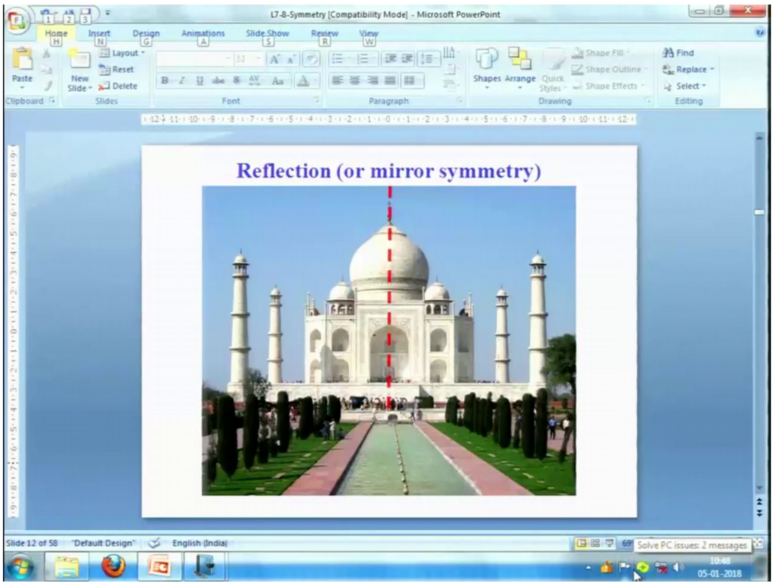

Now, get back to third class. So, this was again an example of Reflection symmetry. So, you can see that Taj Mahal is built in such a manner. So, that you have a mirror plane across Taj Mahal, so, but there are a lot of other objects, which do not show this kind of symmetry or our own human body for example.

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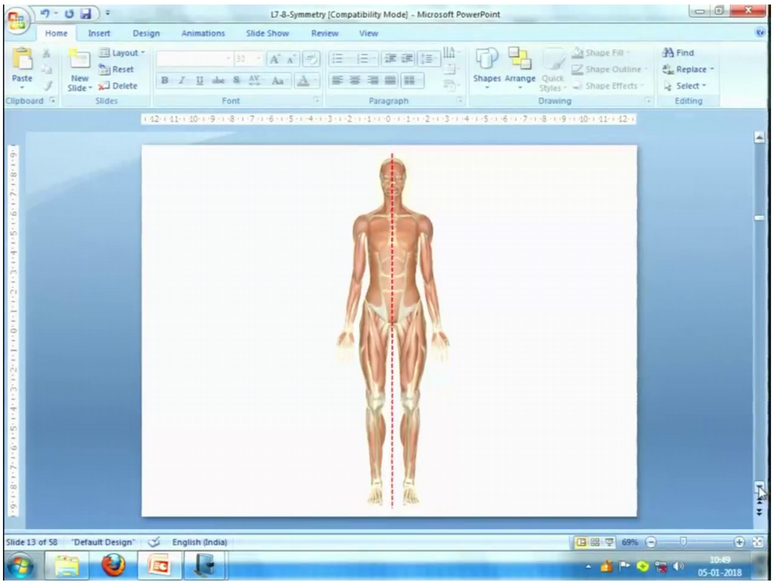

Has this symmetry, in case of human body you can see that, we are nature has made a fairly symmetric. So, that you can draw a vertical mirror plane across us and the left and right side unless we have any physical deformity. We are fairly symmetric in nature.

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So, now let us begin with lecture 8.

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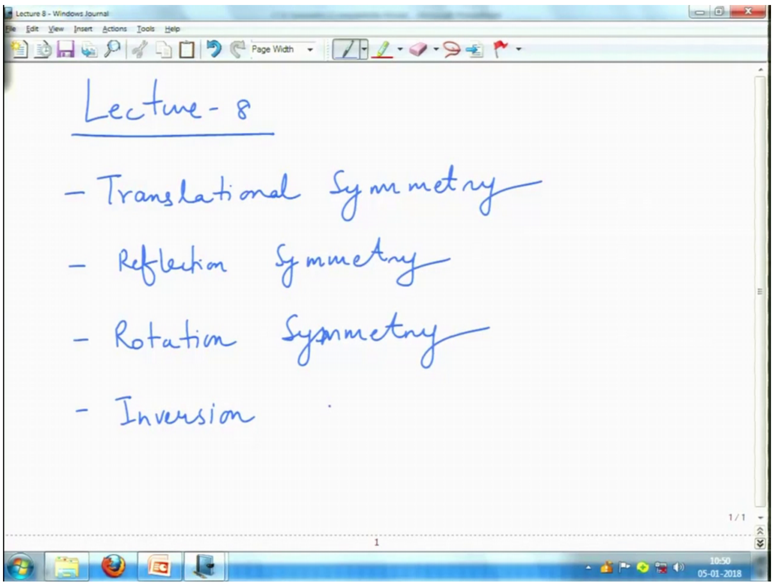

So, we have seen Translational symmetry. We have seen Reflection, we have seen Rotation symmetry and the third fourth one is Inversion and Inversion is an operation, which is basically let me now go to.

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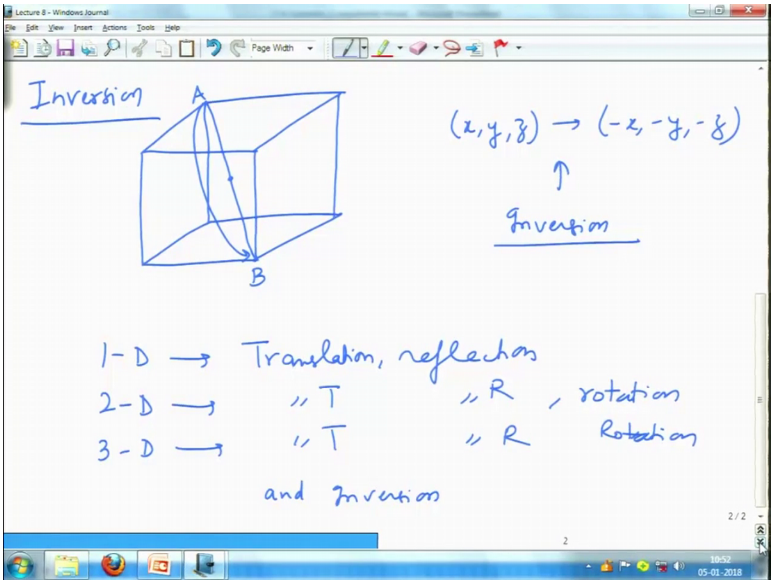

So, Inversion is an operation for example, I draw a cube here. So, in a simplest of the, in the simplest of the term; so, this is a cube diagonal alright, this is a cube diagonal, let us say this is A B ok. So, the centre of the cube is the centre of Inversion and you are basically bringing this point across in such a fashion. So, that you bring it to B. So, basically your point x, y, z becomes minus x, minus y, minus z.

So, this operation is called as Inversion and this is an aspect which is found in 3-D crystals ok. So, if I now come back to. So, this is called as sorry Inversion. So, if I now come back to symmetry 1-D crystal show Translation, Reflection at best ok. So, they may only show translation they may not show Reflection depends upon the motif. 2-D has Translation, Reflection and Rotation. 3-D crystals have Translation, Reflection, Rotation and Inversion. So, T, R this is rotation, T, R let us say Rotation and Inversion ok.

So, now let us get back to the crystals.

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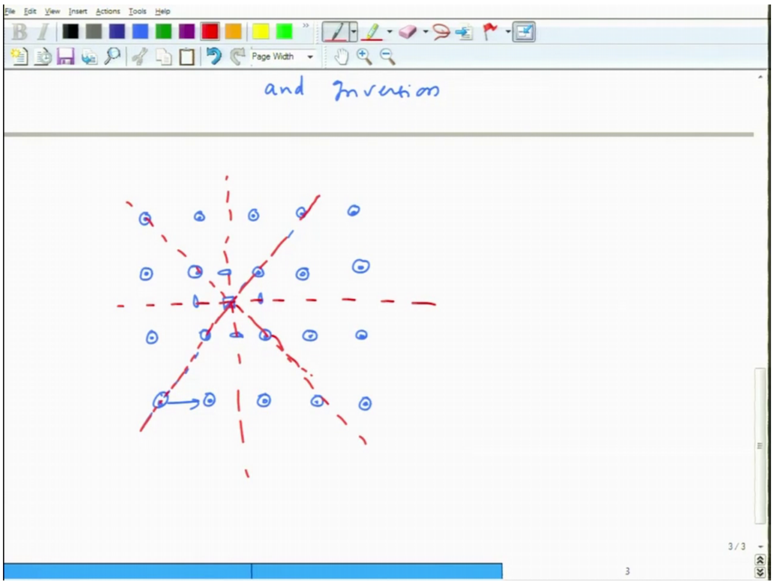

So, in some sense, let me draw a set lattice now here. So, just to summarize now that particular point which I was trying to make ok. So, if I put a motif like this in this case, ok. So, it has a it has a Translation symmetry, you can see, it has a Translation symmetry, it has a 4 fold, it has a 2 fold, it has mirror plane like this. Let me just choose a different colour perhaps. So, it has a mirror plane like this, similarly it has a mirror plane in the other fashion ok, it has a mirror plane here and it has a mirror plane ok. So, these are the 3 symmetries you can see, which are present. So, this is; obviously, case of 2-D and if you draw in 3-D you will have Inversion as well present.

So, now what you can do at home is, find symmetry in alphabets, one of the simplest thing you can do.

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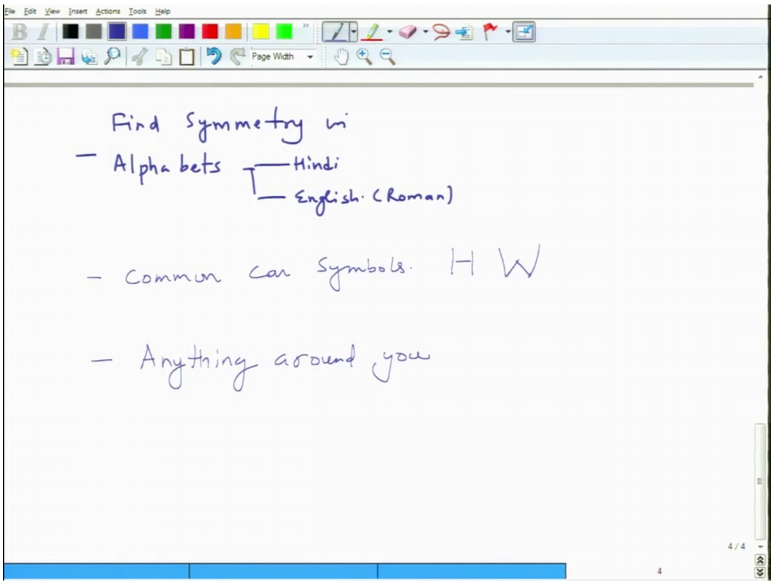

So, you can try both Hindi and English alphabets. You will find that English alpha or Roman alphabets are it is a roman ok, you will find that Roman alphabets a little bit more symmetric as compared to Hindi alphabets. You can use common car symbols around you. So, you can see Honda. So, you will have Honda H, Wolksvagen W and so on and so forth. So, you can try it doing that and then anything around you. So, when you walk just try to notice the symmetry, what are the syllable symmetry elements that are present around you. So, now, we come back to crystal systems. So, now, we come back to Basis of Classification of Lattices into Crystal Systems and 14 Bravais Lattices.

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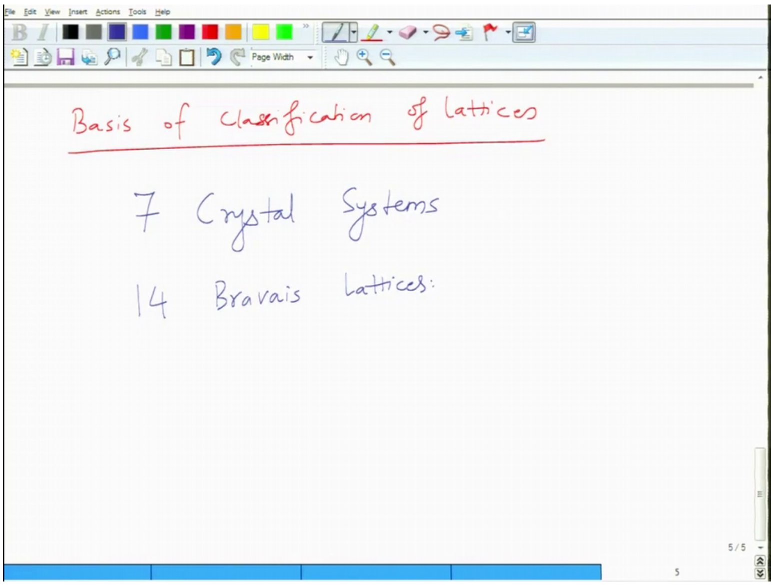

So, we saw that we have 7 Crystal Systems and we have 14 Bravais Lattices ok, you do not have most 20.

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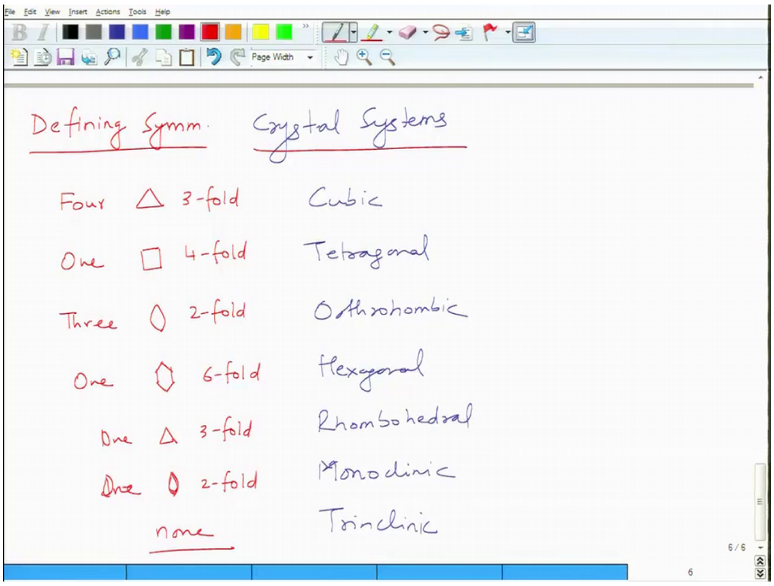

So, if I now say, so, let us say, I make 3 columns, Crystal Systems I make. So, of course, you know the lattice parameter relation, I will not write that now and then I write what is the Defining Symmetry? So, of course, it can be in a little bit more detail, but for the sake of this course which is very. So, Crystal Systems are Cubic, Tetragonal, Orthorhombic, Hexagonal, Rhombohedral, Monoclinic and Triclinic. Now, if I dra[w]- write the symmetry in the left. Cubic has four of 3-fold, basically four 3-fold access. I will come back to what you mean what we mean by this. Tetragonal must have one fourfold at least. So, one 4-fold, if you have, if Tetragonal does not have one 4-fold, which could be there because of motif, then it is not called as a Tetragonal crystal ok. So, for example, a cube if it does not have four 3-folds, even though it may look like a cube, it is not a cube ok.

Similarly, let us go to Orthorhombic. Orthorhombic must have three 2-fold rotations. If it does not have 3-fold rotations, Orthorhombic crystal, it is not Orthorhombic crystal. In case of Hexagonal, you have one 6-fold mandatory and in case of Rhombohedral, you have one 3-fold and in case of Monoclinic, you have one, let us write one here one 2-fold and in case of Triclinic, you have none. So, these are the Defining Symmetries of Cubic, but there are a lot there is a lot more to symmetry, we write things like space groups and because it is not only Rotational symmetry, which is taken into account for crystals, it is also Rotational symmetry Mirror Mirror planes something called a glide and screw which which are defined by basically atomic arrangement in the crystals.

So, you write things like point groups and space groups for for materials, but we do not have time for all that. So, what I just wanted to tell you; that, the basic defining the basic criteria will defined into 7 crystal systems is this, Cubic must have four 3-fold; anything anything else is possible only beyond that, only when it has four 3-fold ok. So, you can have further final classifications in the Cubic Cubic system, but it must have four 3-fold axis; Tetregonal must have one 4-fold, Orthorhombic must have three 2-fold and so on and so forth. So, these are the Defining Symmetry element, for each of these. Now let us see, let us begin with Cubic ok.

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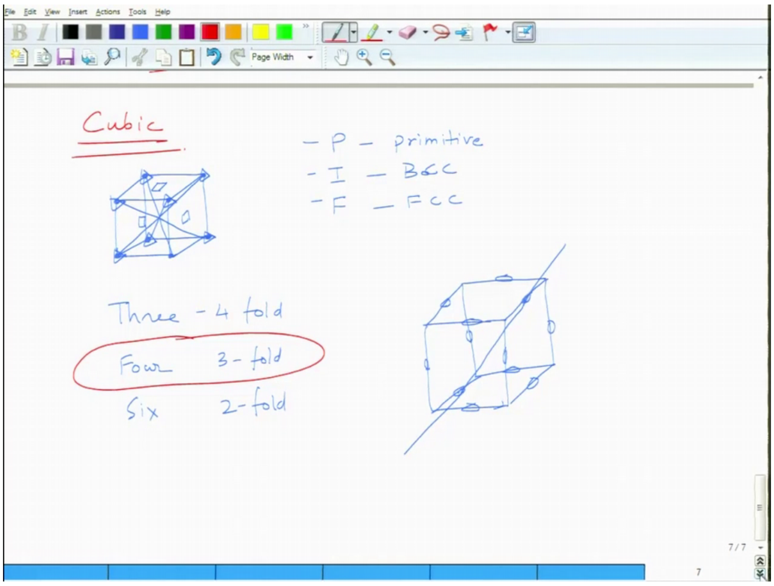

So, let us begin with Cubic first. So, cubic we know, it is like this and we can put the motif like this. This is the simplest and clearest motif. So, of course, we have here options of P, I and F. I discussed that in the last class. P is primitive, I is BCC and F is FCC face centred cubic. So, we can see that, there is no n centred cubic, we will discuss that later. So, Cube typically has three of 4-fold, let us write this 3 as three. So, here here and here right, are the 3 faces are equivalent. So, it has three 4-folds; it has four 3-fold along the body diagonal, this is one, this is another right, because at 8 corners right, 8 corners two of them can be connected with one diagonal.

So, all these will have 3-fold rotation around that axis. Four 3-fold and how many it also has by the virtue of it having 3-folds and 4-fold, it also has 2-fold. So, it has six 2-fold and those are nothing, but I will not draw it there, I will draw it separately all right. So, if I connect this point to that point yeah. So, if I connect this point to that point and if I provide a rotation around that, it will be 2-fold. So, I have 6 of these face. This is not even a face diagonal right. So, equivalent to face diagonals; so, 6 of these will provide you six 2-fold rotations. So, these are written as, here, like this ovals ok. So, twelve of these divided by 2 will be six 2-fold, but the Defining Symmetry is this now. So, this is how cubic symmetry will be. In case of Tetragonal; so, I will give you just few examples, I will not get into all the details.

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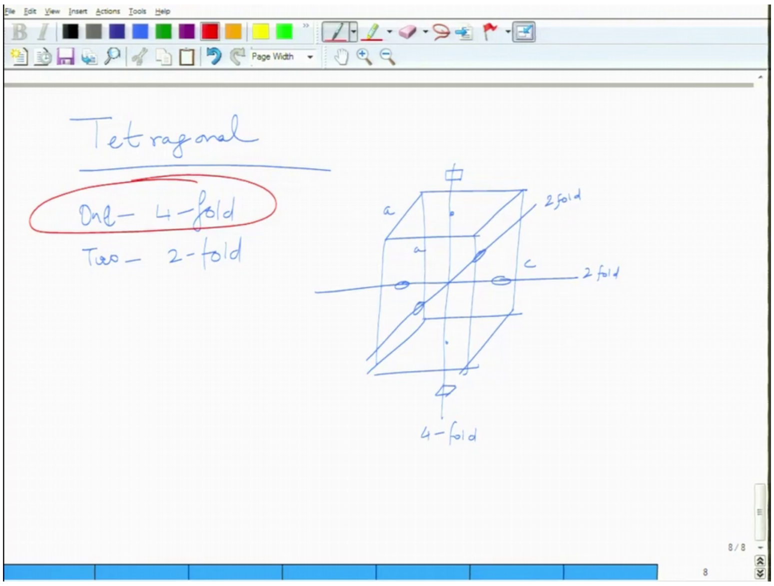

So, Tetragonal all; so, Tetragonal of course, we know that, there is a primitive Tetragonal body centred Tetragonal. So, Tetragonal will have one one of 4-fold and if you have one or 4-fold, it will also have two of 2-fold. So, that also you can see that, if you when you draw a Tetragonal crystal. So, this is your Tetragonal crystal. So, if you draw line like that. So, this is a, a and c. This will give you a 4-fold rotation all right. You will get a 2-fold rotation from here, 2 fold and from another shelf. It is axis 2-fold, this is 2-fold, 2-fold and this is and Defining one is one of 4-fold and similarly you can see in case of Orthorhombic and Hexagonal. So, in case of Orthorhombic, we have seen. So, I will not get into details of this.

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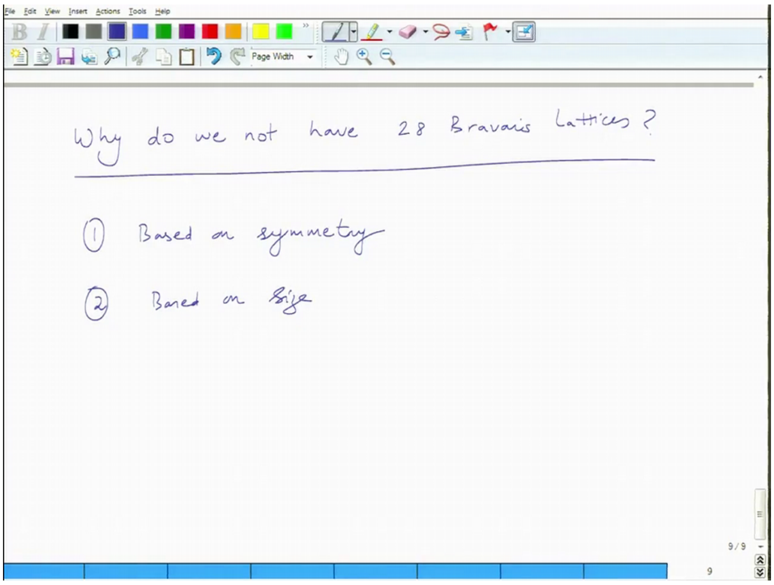

Now, I will come to the next point, that we missed early that we talked about earlier is why do we not have 28 Bravais Lattices? What is the, so this is the; you can say minimum symmetry that is required. So, you may have a 4-fold, you may have a 3-fold, but if you lose a 3-fold, it does not see that is defined by motif ok. If you lose a 3-fold, it does not remain a Cube. So, Crystallographically speaking, a Cube is a Cube, only when it has four 3-fold rotations possible, otherwise it is not it looks like a Cube, but it does not give you the repetition of a cube, because remember a Cube must Cube must be brought into the Cube must be brought into the position of self coincidence by performing the minimum symmetry operation.

So, for although 4-fold and 2-fold can bring it into a cube shape back into it, but 3-fold will not be able to; so, which means it has lost one symmetry element. So, that is the minimum depending. So, if you are able to perform a four 3-fold operations on a cube, then 4-fold, 2-folds are automatic, but having 4-folds and 2- folds do not necessarily mean a 3-fold is automatic. So, that is why we choose the Minimum Defining Symmetry ok. So, why do we not have 28 provides lattices? And we have only half of this, we can see we have only 20 14. So, what are the reasons? The reasons are first reason is, that is based on symmetry; second reason is based on based on size, that is, the other possibilities convert into something else because of symmetry because they fulfil the symmetry criteria of other lattice. Similarly, as far as possible we must be choosing a smallest size, smaller size with best possible symmetry.

So, smallest size and best possible symmetry leads to other combinations. So, that the possibilities convert into something else. So, let us see some cases for that. So, we have a Crystal System Table and we have Bravais Lattices.

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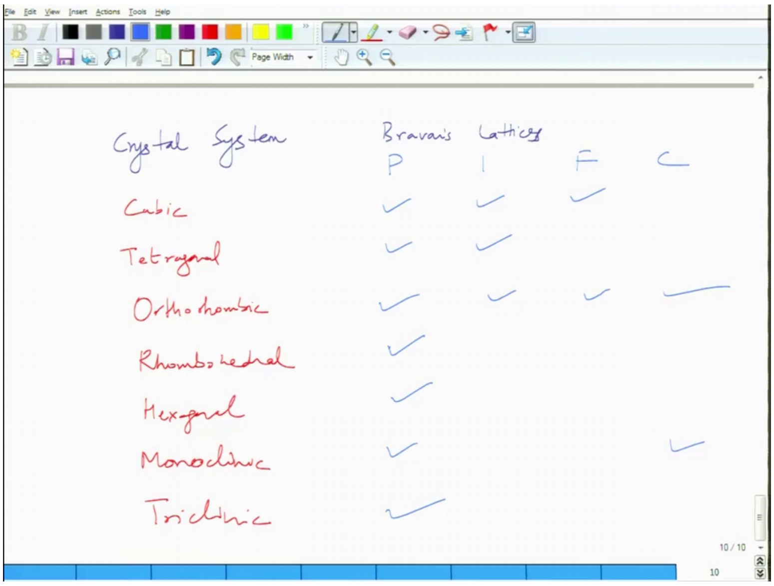

So, we can see that, we have here Cubic, again Trigonal, Orthorhombic, Rhombohedral, Hexagonal, Monoclinic and Triclinic. So, we define these into and the classes or let me write here P, I, F and C. In case of Cubic I have these two, Tetragonal I have only these, Orthorhombic I have all of them, Rhombohedral only P, Hexagonal only P, only monoclinic has P and C and Triclinic does not have any of them. It has only P nothing else. So, now, first let us take the example, one example.

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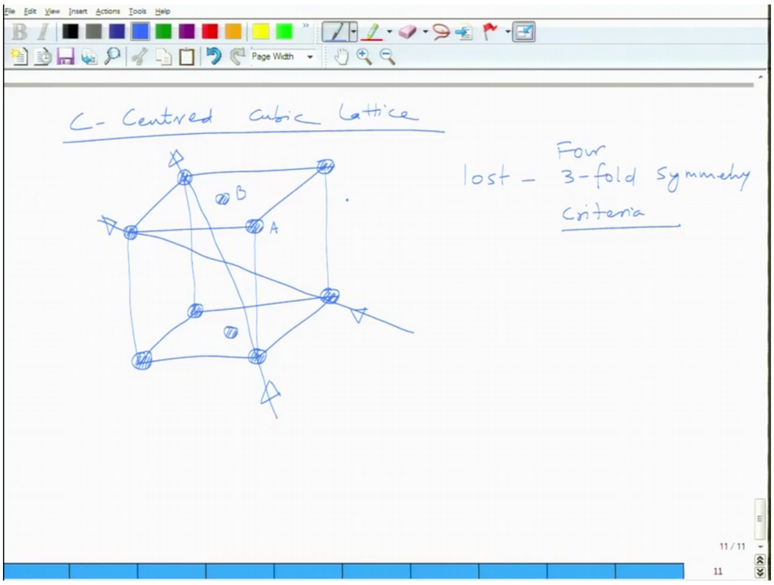

Why is C-Centred Cubic missing? So, C-Centred Cubic Lattice ok. So, let us draw the C-Centred Cubic Lattice. This is a cube. I am going to draw all right. So, this is a Cube, which I have drawn, C-Centred will be one atom here, another atom there, all right.

Now, the question arises is; does it have what is the Defining Symmetry? Four 3-folds. So, the question is; if I now draw a 3-fold from here to here or a 3-fold from here to here, does it have a 3-fold? Will I be able to bring it into self coincidence by performing a threefold rotation here? We will not be. So, what have we done here? We have lost the 3-fold symmetry criteria. For 3-fold symmetry criteria, as a result, although it looks like cube, it is not a cubic system, but then what it is? Is it a lattice to begin with? See, what was the definition of a lattice? This is point A and this is point B, both must have same identical neighbourhood.

So, we can see that B has four neighbours, here A also has four neighbours, because one will be here; another will be here; another will be here ok. So, it is a Lattice. So, what is it then? What can we reconstruct out of it? So, it must be something. So, what is it? So, what is it is, we can now, what we do is that, we draw 2 unit cells ok.

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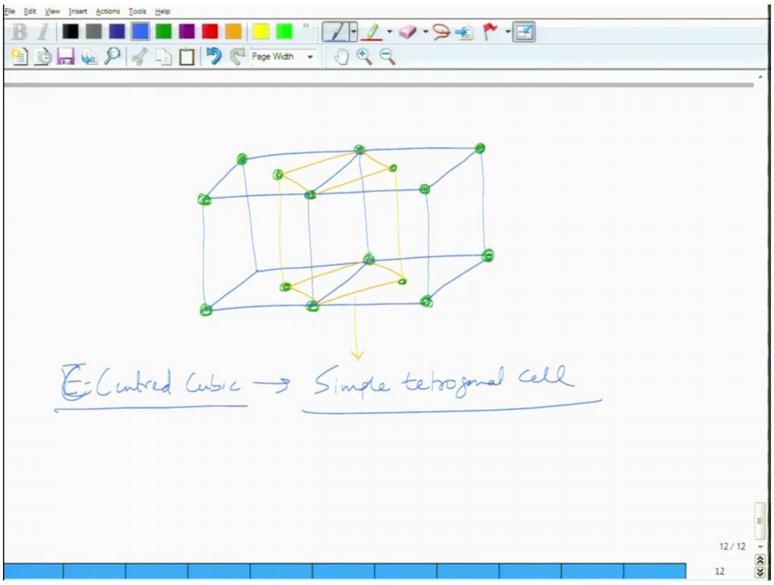

Now, let us put these atoms ; one atom here, one atom here, another here and another here. If I construct let us say a unit cell like this, which is this yellow or sorry orange coloured unit cell, what you get here is a Tetragonal. So, we can form a simple Tetragonal cell, which has a smaller size which has a smaller size, n-Centred Cubic is basically, n-Centred or C-Centred cubic basically is nothing, but a Simple tetragonal cell ok. Similarly, so, we can see that, if I go back to if I go back to previous slide, I can see that, this is that is why it is not there because it is yes. So, we will see the other opportunity other possibilities in the next class.

So, basically just to summarize, this class, we have seen that there are few Defining Symmetries in Crystals; Translation Symmetry, Reflection Symmetry, Rotation Symmetry and Inversion symmetry. These are followed in 3-d cases and as we have seen that Bravais Lattices Crystal Systems are certain Defining Symmetries, then Bravais Lattices are chosen out of those crystal systems, based on their size and symmetry. We have seen one example, we will see more in the next class ok.

Thank you.