**Project of Materials (Nature and Properties of Materials: III)**
**Professor. Ashish Garg**
**Department of Material Science & Engineering**
**Indian Institute of Technology, Kanpur**
**Lecture 21**
**Slip Systems**

So, welcome again to the new course. Welcome again to the new lecture of the course, Properties of Materials. So, let just briefly see what we did in the last class.

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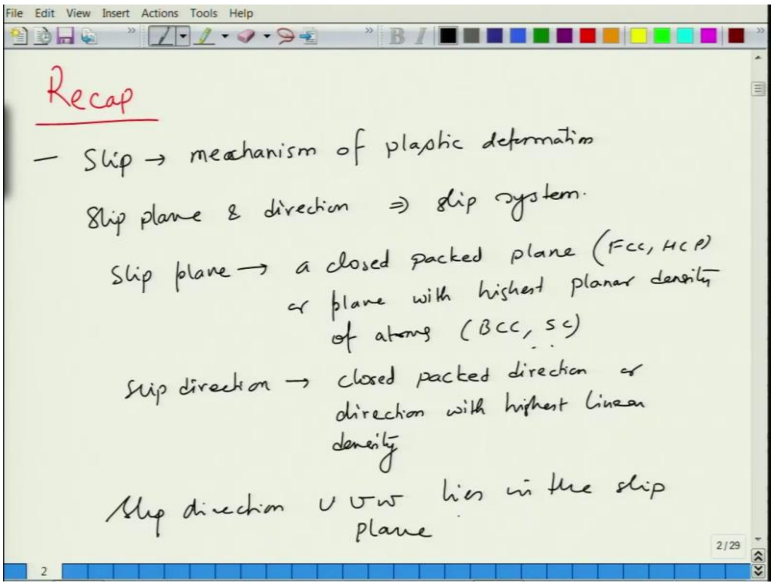


So, in the last class what we did was, we explored the phenomena of slip which is a mechanism of plastic deformation. So, slip is basically slipping of a bunch of atoms against other bunch of atoms across a slip plane along a direction. So, the combination of the slip plane and direction, this gives rise to what we call as slip system.

So, slip, we looked at the various characteristics of slip plane. So, the slip plane is generally, a closed packed plane for solids which are close packed or plane with highest planar density of atoms. So, basically if you have a FCC or HCP system, then you have a closed pack plane, but if you do not have FCC or HCP, if you have BCC simple cubic, etc, then you will have plane with the highest density.

And then you have a slip direction and this direction is again a closed pack direction or if you do not have closed packed direction then, direction with highest linear density. So, essentially if you consider that touching is sphere model then, in every solid you will have by enlarge a touching, a close packed direction and this closed packed direction will lie within the slip plane and the slip direction u v w lies in the slip plane h k l.

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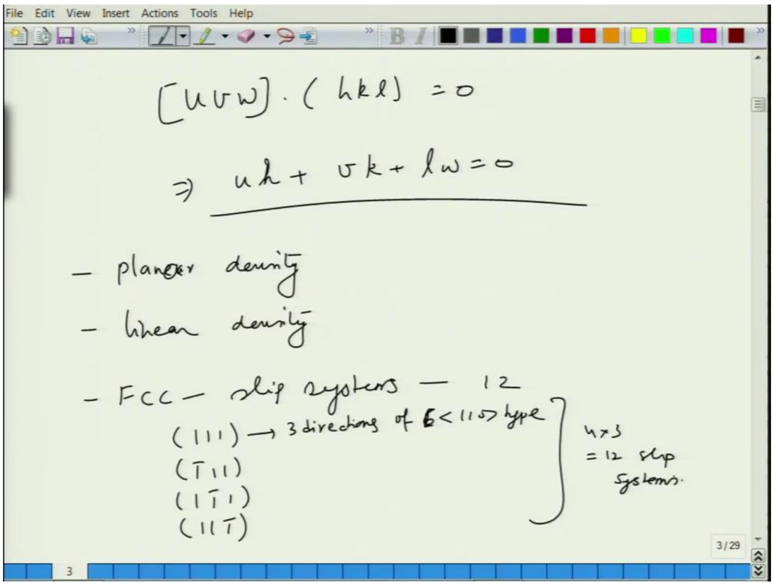


Implying that u v w dot h k l is equal to 0. That means u h plus v k plus l w is equal to 0. So, the dot product the 2 is equal to 0. So, basically this is what a slip plane is. Slip system definition will be. Now, so what we did was, we worked out how to, how to calculate the planar density?

We took one example and then we also looked at the linear density, longer direction and then we also did FCC slip systems which are 12. So, for 1 1 1 type planes. So, 1 1 1 bar 1 1 1, 1 bar 1 1, and 1 1 bar 1. Each of these will have 3 directions of, let say 1 1 0 type. So, now if you have 1 1 0 type direction, what it means is that you have to have indices which have dot product equal to 0. So, this will become 4 into 3. This will give you 12 slip systems. You can do the similar exercise for BCC.

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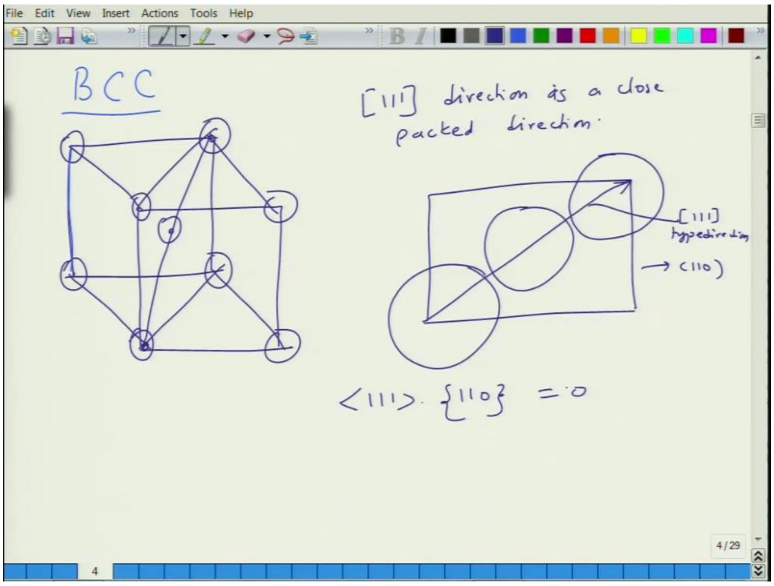


Now, for BCC, things are little different. So, this is a BCC system. In BCC, you have atoms here, here, here, here, here, here, here and then one at the centre. So, in BCC what happens is that, this direction 1 1 1. So, the direction 1 1 1, this direction which connects this atom, this atom. So, 1 1 1 direction is a closed, closed packed direction the highest linear density.

So, if you take for example, this particular plane. So, in this particular plane, let us say, this is a, this is 1 1 0 plane. So, you will have one atom sitting here, another atom here, another atom here and this will constitute the 1 1 1 direction. So, this will be 1 1 1 type direction. So, basically if you have, so if direction is 1 1 1 type, the plane is 1 1 0 type or rather you can write these.

Then such dot product is equal to 0. So, but 1 1 1 direction does not only lie in 1 1 0 plane, it can also lie in other planes. So, for example, so this 1 1 1 direction can have, so these are, so the combinations of 1 1 1. So, if you look at 1 1 1 dot h k l that is equal to 0.

Basically, h plus k plus l should be equal to 0 for 1 1 1. So, which means you have various combinations. First combination could be h plus k is equal to minus l. Another combination could be h is equal to minus k and l is equal to 0 or one of these is equal to 0.

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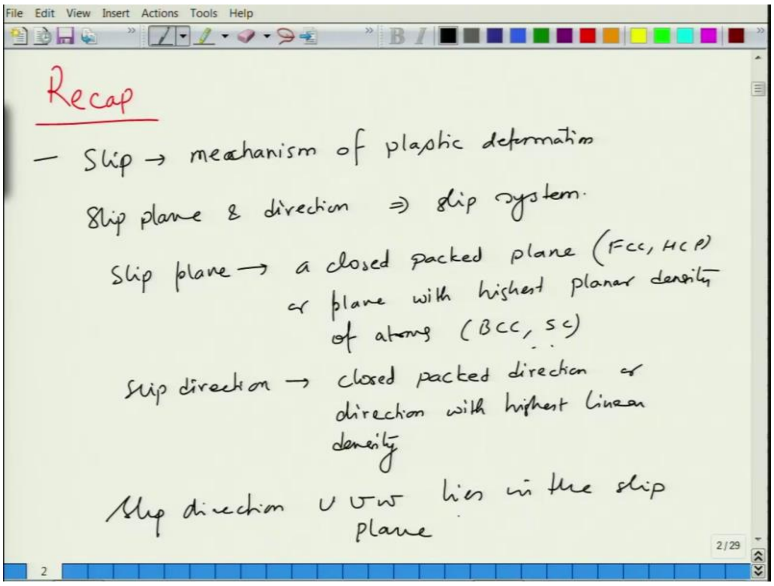


So, basically if you work out the combinations, you will see that you have 1 1 0 type of planes. So, you can have 1 1 0 meaning, you can have 1 1 0, you can have bar 1 1 0, you can have 1 0 bar 1, you can have 0, 0 bar 1 1. So, some of these planes 1 1 0, bar 1 1 0 and then we can also have 0 1 1, 1 0 1.

So, these 6 planes will have these directions. So, 1 1 0 for instance can have bar 1 1 1 and 1 bar 1 1. Similarly, bar 1 1 0 can have 1 1 1 or bar 1 bar 1 bar 1. So, you can keep doing the maths and you will see that it will have 6 planes into two directions. So, 6 is the planes and each plane will have 2 directions because if you look at this 1 1 0 plane, this is the 1 1 0 plane

This is the central atom, this is the corner atom you have one atom here. So, you can have one directions as this direction and another direction could be this direction. Both of them are 1 1 0 type of direction. So, both of them we can we can say are 1 1 0 type, 1 1 1 type of directions. So, you have 6 planes each plane containing 2 directions which means you will have 12 slip systems.

But this is only for 1 1 0 plane. So, 1 1 1 direction can also make a dot product with other planes for example. If you have for example, 1 1 2 kind of plane then we can have h k l could be 1 1 bar 2 for this direction. You can also have 1 2 3. So, h k l in this case could be 1 2 bar 3. This is for 1 1 1 direction, but if you have multiple cases of 1 1 n direction, you will have different combinations.

So, if you do the maths for number of non-parallel. So, these are you can say 6 non-parallel planes, 6 distinct planes. So, number of non-parallel planes for 1 1 2 will be 12. So, you can work out 12 combinations. So, the way you will go is you will write 1 1 2, then 1 2 1, 2 1 1, then bar 1 1 2, 1 bar 1 2, 1 1 bar 2 and so on so forth, you keep writing this and then you will have 12 combinations of non-parallel planes so and so on. So, and so on, so each of these planes will contain one direction.

So, they contain only one direction. So, number of directions in them is equal to only 1. So, total slip systems of 1 1 2, 1 1 1 type will be equal to 12. So, we worked out 12 earlier. So, we have 12 for this, 12 for this and then you can also have 1 2 3 plane.

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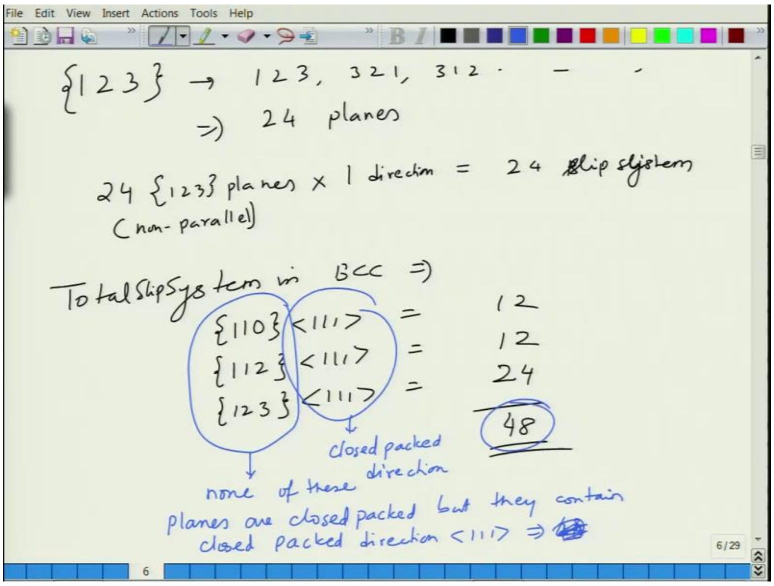


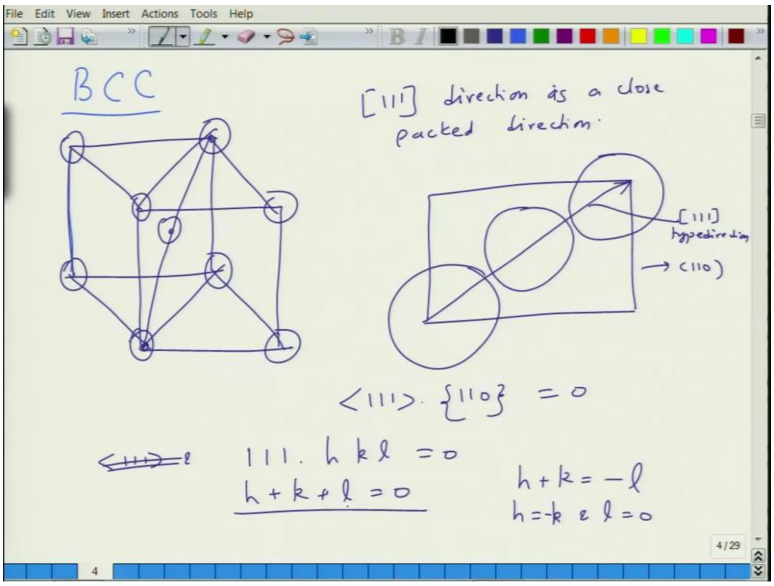


So, for 1 2 3 plane, again you can work out various combinations. So, you can have 1 2 3, 3 2 1, 3 1 2 and so on and so forth, then you put the minus this is. So, you will work out total of

24 planes. So, 24 of 1 2 3 planes which are non-parallel multiplied by each plane containing one direction.

So, one direction, one distinct direction. This will give you total number of 24 slip systems. So, total slip systems in BCC will be first one will be 1 1 0, 1 1 1, this is 12. Second is 1 1 2, 1 1 1. This is 12. Third is 1 2 3 into 1 1 1. This is 24. So, total of 48 slip systems in BCC. Now only difference is in BCC none of these planes is closed packed. They are the planes with high atomic density. So, none of these planes are closed packed.

They are the planes which happened to contain, but they contain closed packed direction in them. So, these are all closed packed directions, but they contain closed packed directions, 1 1 1. So, total of 24, 48 as we said slip systems.

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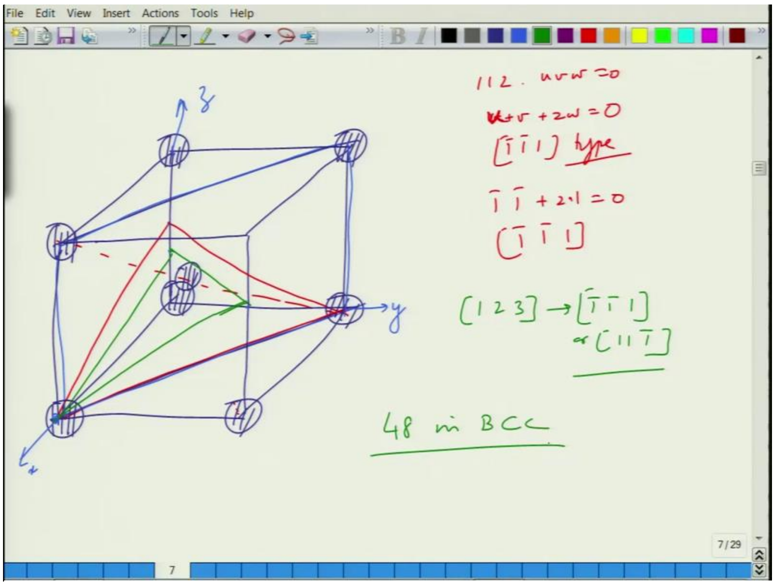


So, you can, you can do this, you can make a geo graph and see it yourself. So, make a cube for instance. So, this is your atom one at the centre somewhere here. Now, 1 1 0 plane, is this is 1 1 0 plane. So, this is the first plane, 1 1 0. Let us say if this is x, y, this is z. We want to make 1 1 2 kind of planes, then we have 1 1 2.

So, 1 1 2 plane would be the plane which would be this plane and this plane contains this direction. So, you have we can say, this direction. So, 1 1 2 goes to through the central atom and there will be in direction which will cut through it. So, this will be 1 1 2 plane.

Similarly, we can have, so 1 1 2 dot you can find out u v w that is equal to 0 and so, u plus v plus 2 w is equal to 0 and then, you can do the maths yourself and so we are saying that, the direction is 1 1 1 type. So, which means u and v are to be minus 1 and w has to be 1. So, that it is equal to 0. So, it is going to be bar 1 bar 1 1 direction, 1 direction. So, you can denote bar 1 bar 1 1 which will pass through this. Another plane is 1 1 2, 1 2 3 plane. So, 1 2 3 will be 1 2 and 3.

So, this will be the plane and you can just cut cross this plane. So, there will be 1 direction lying through this as well. So, 1 2 3 plane will give you a direction which is again bar 1 bar 1 1 or 1 1 bar 1. So, this will be the way in which you can determine the number of slip systems. So, total number of slip systems is 48 in BCC. But none of them are closed packed planes. They do contain closed packed directions in them though.

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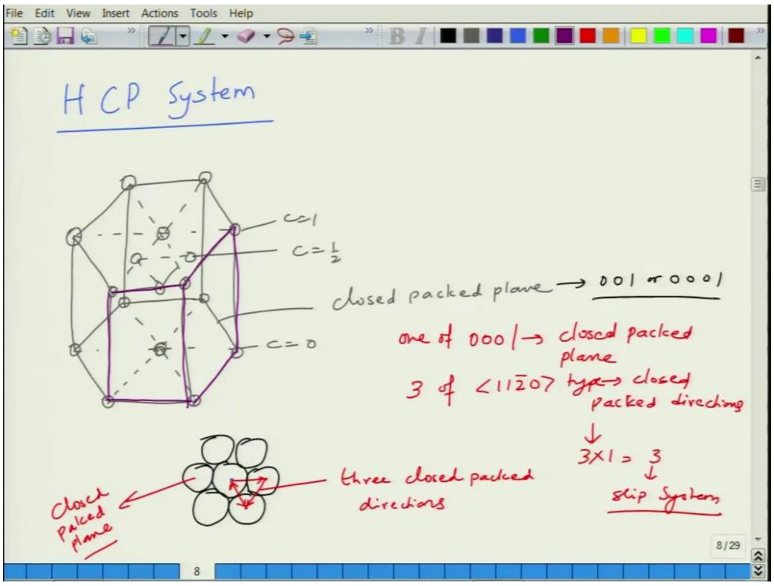


Now, let us look at HCP. HCP systems as we know, is given as this kind of structure. So you have one atom here, another atom here, another atom here, another atom here and then one at the centre. Then, now, in this case and of course you will have two atoms somewhere in between 1 2 and 3 like this. So, these are at C is equal to half. These are at C is equal to 1 and this is C is equal to 0.

So, in HCP, closest packed plane is this plane. This is the closest packed plane whose indices are 0 0 0 1 or 0 0 1. So, this plane is the closest packed plane. If this is the closest packed plane, the directions which are closed, so if you just now bloat it this is how it is going to look like. So, this is the closed packed planes, plane. In this case, there are only 3 closed packed directions one is this, second is that and second is, third is this. So, 1 2 and 3 or this.

So, these are the 3 closed packed directions and this is closed packed plane. So, basically the directions which are so, if 0 0 1 plane is the closed packed plane, the directions which lie in them are of 1 1 bar 2 0 type. These are closed packed directions. How many of them are there? There are 3 of them. So, there are 3 of these directions, one of this plane. So, slip systems will be 3 into 1 total of 3 slip systems.

So, number of slip systems in HCP will be 3, if you consider the closed packed directions, closed packed plane and closed packed directions. But there are other planes as well which contain these closed packed direction. So, for instance, this plane can contain this direction. So, all these planes they will contain this direction.

So, they will also contain these. So, likewise you can form various solutions. So, total number of possible slip systems which can, which contain these closed packed directions could be up to 12 in FCC. But out of those two, three are the most preferable. Others are sought of secondary slip systems. So, essentially if you now tabulate this information.

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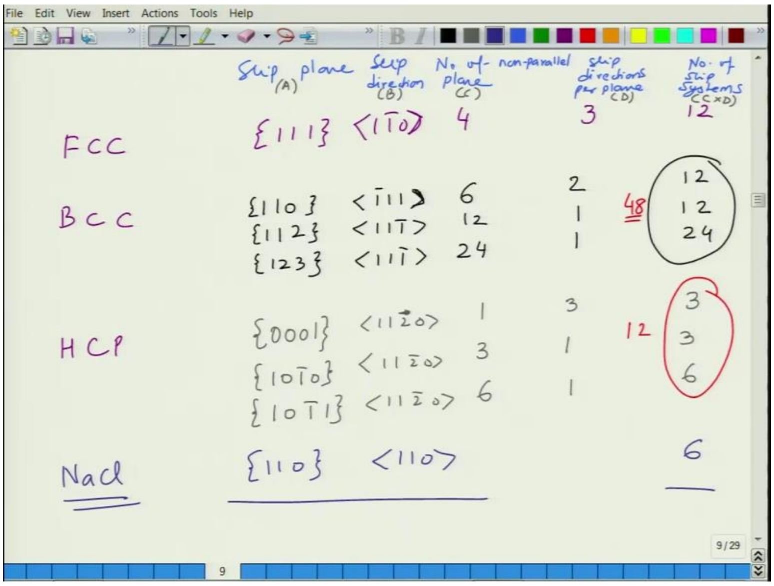

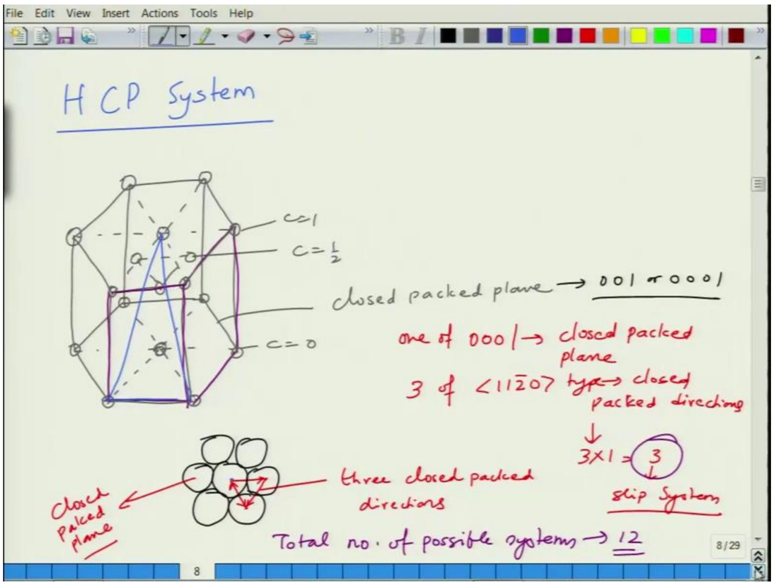


So, we have a FCC structure, we have HCP. So, for BCC, we see that the slip plane, so if you write slip plane, number of non-parallel planes, slip directions per plane and then number of slip systems. So, for FCC, we know that the plane is, so we can just write it little lower. So, this is FCC. So, for FCC, we know the plane is 1 1 1 and the direction is 1 bar 1 0 or 1 1 0 type of direction.

So, each contains 3 directions. So, there are, slip plane. I should have written one column for slip direction, the slip direction. So, let me just move it here. So, this is 1 bar 1 0. Number of planes, 1 1 1 type planes are 4. Number of non-slip direction per plane is 3 and this will make it 12 and then we have BCC.

In BCC, we have 3 combinations. One is so, first one is slip plane could be 1 1 0. Second is 1 2, 1 1 2. Let us say, let us go in the order and third is 1 2 3 and the directions could be 1 1 bar 1 or in this case it would be, bar 1 1 1. In this case, it would be 1 1 bar 1, in this case, it would be 1 1 bar 1. So, number of non-parallel planes, we can say is 6, 12 and 24 for 3 of them.

Number of directions they contain is 12 1 1. So, this will give you 12 slip systems. This will give you 12 slip system, this will give you 12, this will give you 24. So, total of you can say is 48 slip systems in BCC. Whereas, in HCP, let us use a different colour now. In HCP, we have planes which are possible is 0 0 1 which is only 1 plane. Then you have 1 0 bar 1 0 plane and then you have bar 1 1.

So, these are so essentially, you have this plane and you also have the plane which is this plane. So, if we consider all these planes, these 3 planes, they contain the directions 1 1 bar 2 0. They also the direction 1 1 bar 2 0 and they also contain the direction 1 1 bar 2 0. There are

3 one plane of this type. Three of 1 0 bar 1 0 type and 6 of 1 0 bar 1 1 type. They contain, so the first one contains three of these directions and these contain only 1 and 1.

So, number of slip systems is 3. So, basically, we can say A, B, C, D and this would be basically C into D. So, it is 3 and 6. So, this will be total of 12 slip systems. So, this is how you can derive slip systems in case of the solids. You can also work out the solids, for example in the case of solids like NaCl, NaCl is HCP. But the slip system, FCC and but its slip system are not same as what you see in case of metals, because in the case the slip plane is 1 1 0 and slip direction is 1 1 0 and this gives you total of 6 slip systems.

So, that is because of, say FCC structured which is not necessarily a closed packed solid. So, this is what we have done in this lecture. We have looked out the, worked out the slip system in these different materials. In FCC, we have 12 slip systems consisting of 1 1 1 planes which can carry 1 1 0 types of closed packed directions. BCC has 48 slip systems. HCP has 12 slip systems.

Now out of these the most favourable slip system are those which in materials which have closed packed planes. So, FCC although it has 12 slip systems, all of those slip systems consist of closed pack directions lying in closed packed planes and that is why they are very favourable slip systems. We will do the phenomena of slip in more detail in the next few lectures after this, thank you.