Materials Science and Engineering
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Lecture - 05
Crystal Planes and Directions: Indexing

Hello friends. Today, we are going to discuss about crystal planes and directions, how we can index them and in hexagonal system cubic system and so on and what is the procedure of indexing and what is the importance of why we want to understand that how to index these planes and directions, we will start with that first.

So, the importance of why we want to understand that why which planes are numbered or how you can name the planes or the directions one of the example is here on the slide that there is a problem called earing in during deep drawing operation.

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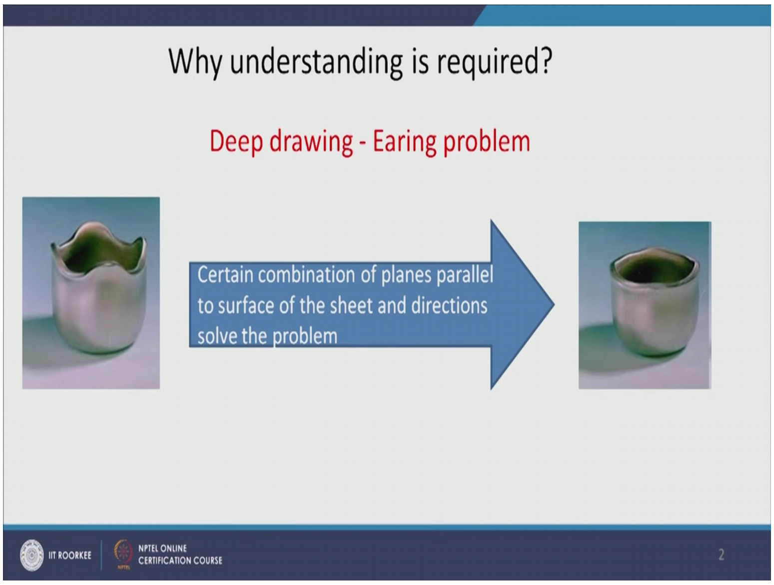

So, basically if you want to make a can for example, beverage cans the Coca-Cola or Pepsi cans which you cold drink cans which you use ok, these are all deep drawing made by deep drawing operation and.

If your which type of planes are parallel to the surface and what kind of directions are there depending upon that you will get a certain problem which is called earring problem and to control this kind of which type of planes and directions are there parallel to the surface and parallel to a certain direction if you do a good control ok, then you can get rid of this earing problem you can understand that when you have earing problem ok.

You have to remove this much material to get a final shape like this also there will be because there are different type of deformation at different part of the cup, you will have thinning of material at certain point and at another point there will be a thick sheet. So, there will be a difference in the thickness of the sheet or or sheet in the cup.

So, which is not a good thing and we will not be able to design any of our part properly if there is thickness difference another example is for electrical transformer if you know electrical transformer this is a core laminated core.

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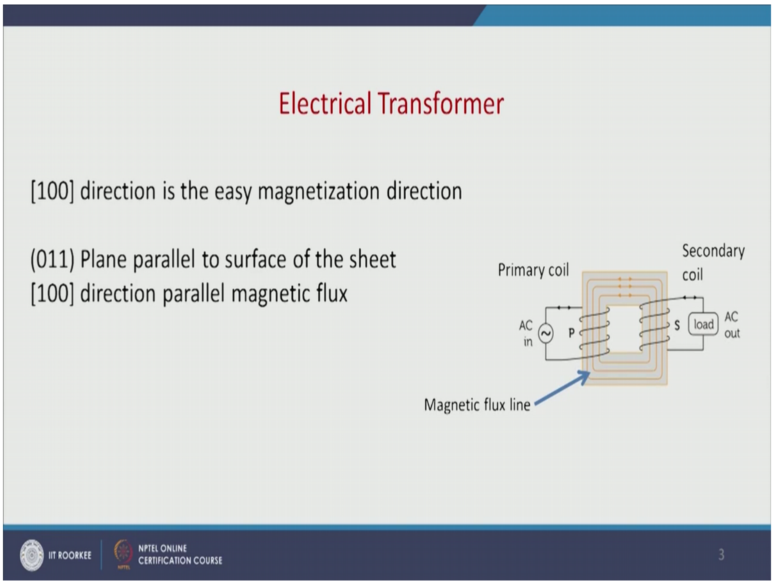

These are primary coils, these are secondary coils and when during ac current, they if it is a it has a 50 hertz cycle; that means, 50 times, it is the polarities changing from positive to negative and because of that there is induced flux through the core which flows as shown by these lines and that induces the current in the secondary coil by experiments people understood that if a 1 0 0 direction of a particular crystal in this case because this is electrical transformer electrical steel is there ok.

So, in bcc materials or bcc crystals 1 0 0 direction is the easy magnetization direction; that means, you can easily have magnetization and you can understand 50 times, it has to magnetize demagnetize ok. So, with each cycle, there will be a hysteresis loop and for in each hysteresis loop, there will be loss of energy ok. So, it will get heated up you will also have losses in the in the distribution. So, there the all these things, we of course, we do not want ok. So, we we know that 1 0 0 direction is the easy magnetization direction. So, I want to have the grains in the this particular material such that the 1 0 0 direction is lying in the direction of the flow of this flux a magnetic flux line.

So that my losses can be minimized and of course, heating of the transformer can also be minimized. So, you can understand that I have to understand these planes and direction ok, in plastic deformation also later on, we will see that some planes and directions are preferred or where the deformation actually takes place in those particular planes in a particular direction ok.

So, understanding of planes and direction that which type of plane I have to give some name to each plane and direction naming is what is you can see here some some name is given like this is 1 0 0 this is 0 1 1 this is 1 0 0 and we want to understand that.

How I can find out all these indexing or name for a plane or direction. So, that is what is this particular lecture is about that how to index planes and direction you please understand thats this planes and direction is all imaginary things, actually only there are atoms arranged in the lattice we imagine that ok, they they are arranged in a particular plane or they are along a particular direction.

So, the idea for this indexing or the the methodology was given by Miller ok, William Miller in 1839, he proposed a system that how you can index, these planes and directions ok; for example, for directions he proposed that you.

He said u v w can be the name and if you enclose them in a square bracket like which is shown here, then it will be direction that is how you can denote the direction family can be denoted by something like this ok.

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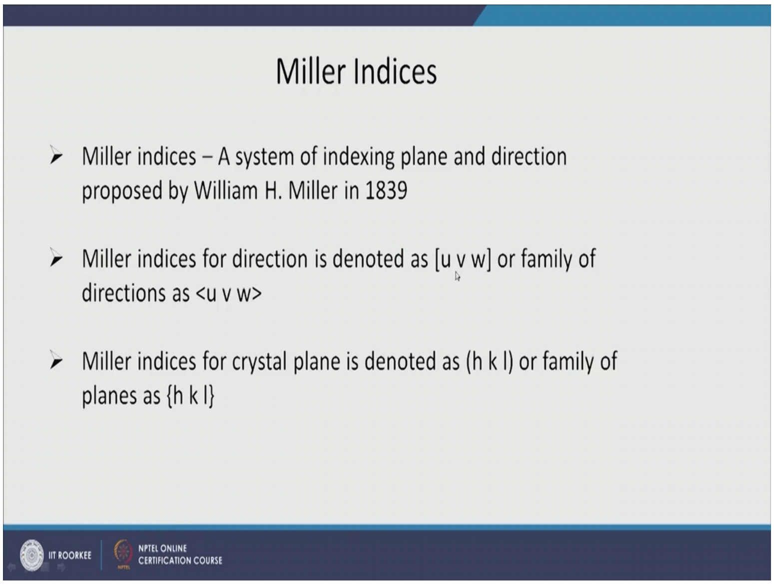

We will we will find out what do we mean by family hk planes can be shown in this parenthesis and family can be shown is in curly phrases. So, we will see, what do we mean by this these are just the notations which are used, which you will use for denoting planes family of planes directions family of directions to start with for example, how to find out the direction let us say that we will take cubic crystal ok, a unit cell of a cubic crystal and we have let us say.

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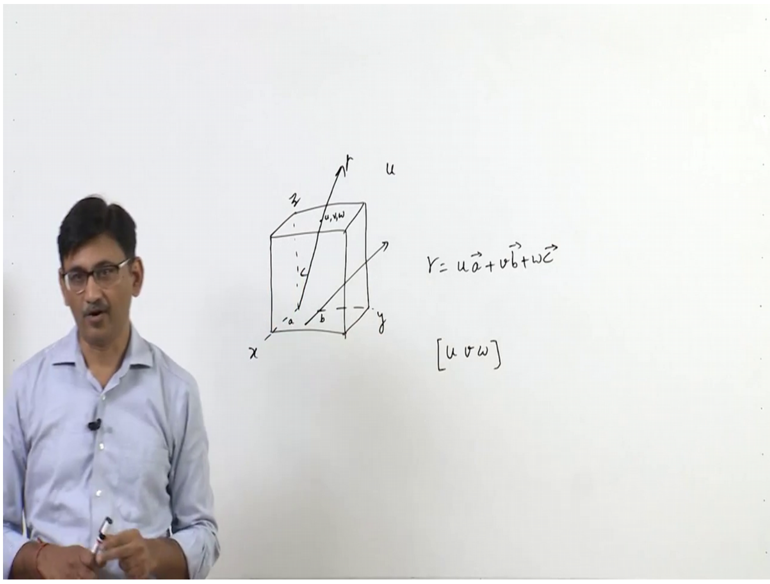

This is x direction, this is y direction; this is z direction along xyz direction I have lattice parameter a b and c. So, if I have to define a vector let us say a vector r which is passing through a coordinate point, let us say u v w suppose somewhere, it is like this, this is my u v w, the coordinate points. So, any vector which is passing from the origin through this point through our vector algebra, I can say that this r vector is it is actually I have to go in all the 3.

Principal directions here will be along a, b and c and if this is u v w, then I will say that r is equal to u a plus v b plus w c. So, this is my vector. So, you can understand that to go from origin to this particular point, I have travelled u times in a direction v times in b direction w times in c direction and this is how you can give the indexing that if this is the u v w, then my indexing of this particular direction r is given by u v w ok. So, in the next slide, I will give you this algorithm for indexing this. So, the first point is that once a vector or direction is given to you u.

If it is not starting or passing through the origin ok, you reposition suppose instead of this vector, suppose I I would have given a vector like this, and now it is not passing through the origin of this particular unit cell.

So, what I can do I can take a parallel vector which is passing through the origin ok, then I can do the all the calculation or how I can get this vector very easily. So, first I will make it to pass through origin if it is not passing through origin then we will find its projection lengths in terms of unit vector a b c as we have just did u a v b and w c there is another.

Way of also finding out the coordinates of this particular vector is a, if you have the coordinates of the starting point and the end point you do the subtraction and the that the that will be the coordinate of this particular direction or vector, but we will not do this we will follow the one which is given by this particular condition.

Now, once you are doing this you will not be a going along these a, b, c direction in integer values ok, sometime you may end up with fractions here. So, we you usually we draw we do not like fractions. So, the this is just a kind of a liking for particular numbers ok. So, instead of fractions he suggested Miller suggested that you can have integers. So, the fractions will be converted to lowest integer values by multi plying by a common factor and then whatever you get you will be enclosed in a square bracket u v w without commas ok.

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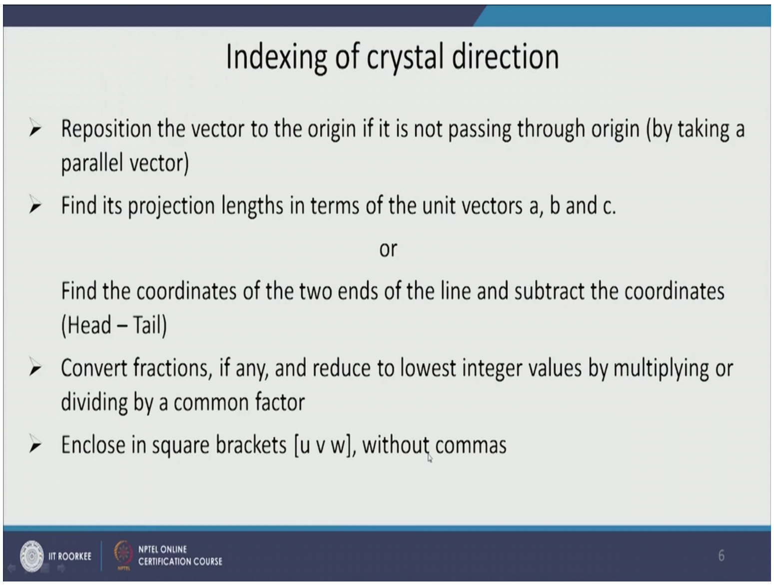

So, that is the whole algorithm for finding out the direction ok, let us say take some examples here which will help us in understanding this.

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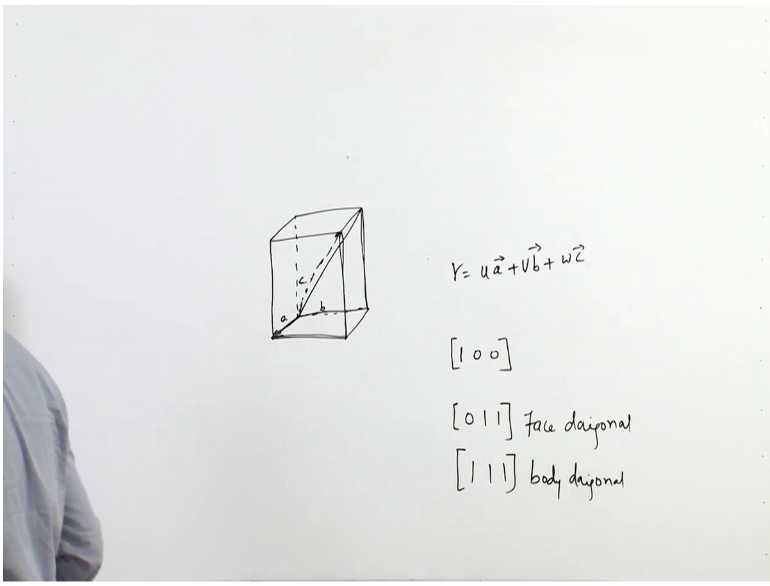

So, again I will make the unit cell here for a cubic crystal ok, we will take mostly the example of cubic crystals ok, we do not want to go into too many complications here right now.

You just want to understand whether, how I can do the indexing. So, suppose I am interested in knowing that what is the indexing of this particular let us say vector or direction and this is a this is b and this is c.

So, again as we saw that you have to do see that how I am going in these 3 different directions. So, to find out the direction of or indexing of this direction I am starting from here this is my starting point now I am going one unit in the a direction ok. So, this is my a direction ok, I will not extend it right now beyond this.

So, I am going one unit in a direction I am not going in b direction or c direction. So, this is one time say and nothing in b and c direction. So, I will write the indexing of this will be 1 0 ok.

I have not put any commas here now we will not keep on doing again and again that let us say again take another little bit more complicated direction let say, I want to find out the indexing of this direction which is joining this particular origin with the this particular point ok, this is the back face of the cube. So, for this I have I cannot go in a direction.

I will be going in b direction ok, one unit, then I will be going in c direction one unit and I will reach there. So, the indexing of this particular direction is 0 1 1. Now, let us say, we take another complicated and by the way, this is this particular one is called face diagonal ok, let us say another one which is joining this origin with this particular lattice point. So, I am starting from here let us say I I draw it with a certain different this thing ok, I want to know the indexing of this one.

From this particular point to the diagonally opposite point here ok, now for this one I will be going because I have to reach there. So, I will be going one unit in a direction one unit in b direction one unit in c direction to reach this point ok. So, I have I am going one unit in all direction.

So, it will be the indexing will be 1 1 1 and this is what we call as body diagonal ok, let us see if we have fractions here instead of these are all in units unit length.

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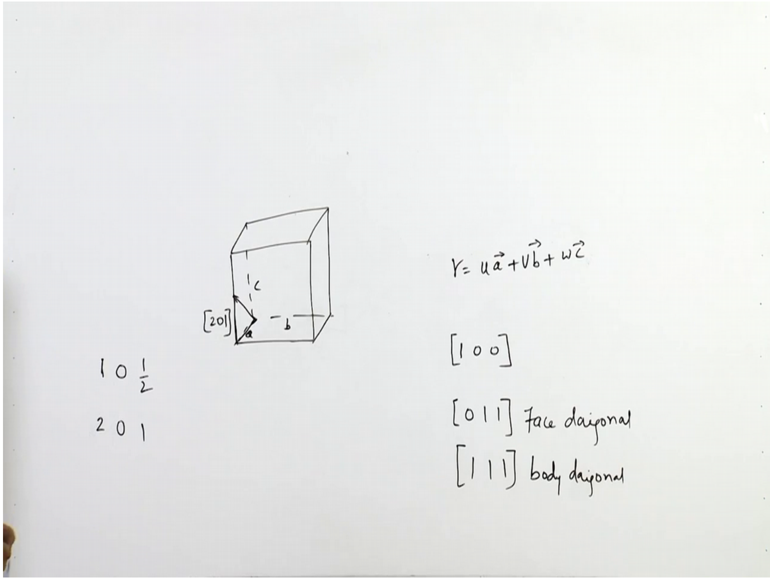

Let us see if we have fraction instead of unit length. Now let us say we are not going up to that let us say we are starting from here and maybe going up to a half distance here. So, this is my direction starting from zero. So, this is again my a, this is b this is c this is origin ok. Now I am going half in the c direction.

So, I have do not have to go in b direction here. Now I will be going in a and then I will be going half in the c direction ok. So, now, I will be not writing directly there, I will be writing that I am going one in a direction I am not going in doing anything in the b direction and I am going half in c. So, now, this is a fraction and as I told you we do not like fractions I want to have integers here.

So, the common factor here is 2 if I multiply it by 2 ok, then I can get rid of this fraction here. So, I will multiply the whole thing by 2. So, it will be to 0 will remain 0 this will become one ok, this particular direction now is 2 0 1.

So, fraction also you can easily handle whatever this thing is fraction is coming you take common factor multiplied by that and get rid of the fraction, the thing you have to remember is that it has to be for the whole calculation it should be the you should get the lowest integers. Now sometime it may happen that you are you have to go in a negative direction.

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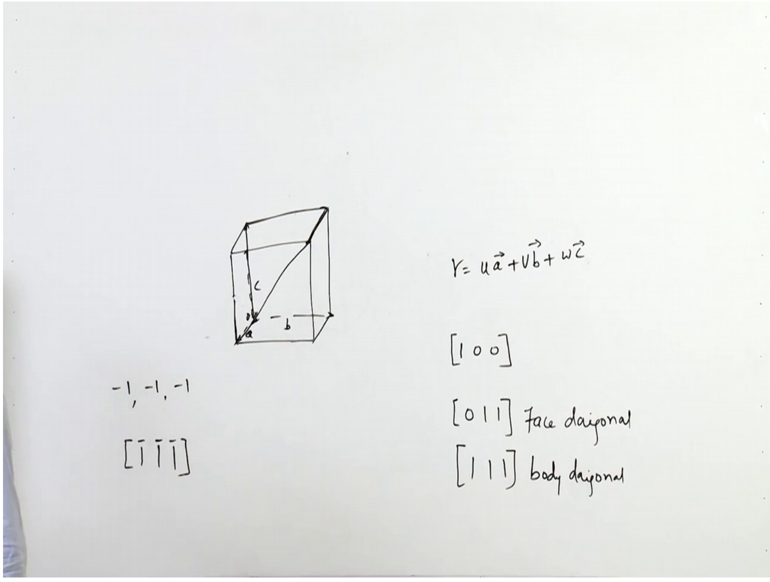

So, let us see, what we will have if we are going in a negative direction.

Suppose my vector is not starting from the origin here and let us say, let us say, I want to know the just opposite vector of the one which we found out here, the style is it starts from here and it is ending here ok, in this case, what we have to do ok, this is my starting point ok. Now, I have again I will do the same thing I will go in a b c along a b c directions ok.

So, first I the, this is the a. So, I am going in the a direction now according to this particular unit cell where this is the origin I am going in the negative direction all these are the positive directions. So, if I am going like this.

Then I am going in the negative direction to the a. So, I am going negative one now this is the positive b I am going in negative b and this is the positive c and I am going in the negative direction to that to reach the end point ok. So, the from origin start of the direction to the end of the direction what path we have to trace that is what we are seeing here.

So, in all these cases we have gone negative negative negative. Now how to write this in were this form of direction I will be writing it like this I will put a bar over the number if it is negative one I will put bar one again bar one bar one again without any commas. So, if you have a if you are going.

Along a negative direction then you have to put bar one bar one bar one to get the direction ok,. So, I think, we have covered different scenarios here the how to get indexing for different direction there can be even multiple ways of finding out the direction multiple directions to find out the indexing for there we will do when we will do the assignments. Now we will come to the how to have the indexing of the planes now again you see that what steps we have to follow here in case of planes we hey we will we will take the intercepts ok.

So, that particular plane what kind of intercepts it is cutting at these 3 different directions a, b, c of the crystal axis then we will take the reciprocal of those numbers. So, this is an additional step here which was not there in the direction case of direction. So, we will take reciprocal of the intercepts after taking the reciprocal if there are any fractions ok, values are coming in fractions.

Again, we will take care of that by multiplying by a common factor to get integers. So, again our law for integers is there ok. So, we do not want we will take first the intercept, then we will take the reciprocal of those intercepts then we will find out the integers.

Of course, we will want to have a smallest integer values here and then we will enclose them in parenthesis without commas again if you have a negative intercept as we saw in the the case of direction also, it will be denoted by a bar over the integer if plane is passing through the origin ok, then we will have a problem because we cannot have an intercept, then you can take a parallel plane of that particular plane or you can shift the origin itself keeping the same sense of crystal axis, this is important ok, when you are shifting the origin the how the axis the positive direction of a negative direction of x is will remain same. We will see all these cases as an example here.

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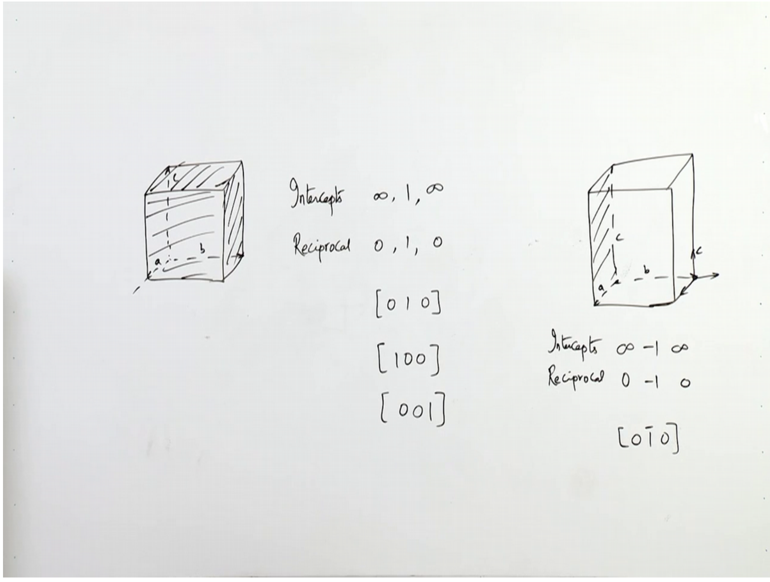

So, let us say again we take a cubic unit cell for the cubic crystal and this is your again a this is positive a b c ok. These are my positive directions for a, b, c ok, let us start with a simple plane first let say I want to know indexing of this particular plane. So, I am just marking it that I am interested in this particular plane ok. So, our first step is to find out the intercepts on the on this particular directions a, b, c ok. So, this particular plane is it is not going to cut a because it is parallel to a, this particular plane is not going to have any intercept on c.

Because it is also parallel to c, but it is going to cut the b axis at unit distance here. So, if I want to write the intercepts in case of a there is no intercept. So, basically intercept is at infinity because both the plane and the direction are parallel, then we say that they are going to may make an intersection at infinity ok.

So, this is going to be at infinity in case of b the intercept will be at one unit distance and in case of c right, now I am putting commas because I am not giving the final index indexing of the planes and for c, it will be again infinity. So, these are my intercepts now.

This is this is why we are taking reciprocal here in case of planes because we again do not like this concept of infinity that how to define this infinity. So, the business of taking this reciprocal in case of plane is just to get rid of this infinity. So, when I take reciprocal here.

This infinity becomes 0; obviously, one will remain one and again this infinity becomes 0. Now in this case because all are integers ok, I do not have to do anything this will remain like this and I can write finally, that what will be the indexing for this particular plane ok.

Now, you can do very quickly that if I want to find out this particular plane let us say I do the etching like this which is cutting the axs at unit distance, then of course, it will be 1 o, similar exercise if you want to find out for this.

So, it will be o o 1. So, very quickly you can see this that you can find out the these 3 planes very quickly now let us see what happens if I want to find out for this plane ok, let me again draw another this thing a unit cell, let us see, I will draw it here you should do a lot of practice with drawing all these things ok.

So, that it does not take much time again a, b, c these are all my positive directions and this is my the origin now I want to know for this plane we have already seen I want to know that what is the indexing of this plane again the same plane the plane like this. It is a parallel plane to this, but the problem is it is passing through origin now how to find out the intercept because it is passing through the origin. So, very convenient way to find out this is that you can shift the origin see origin is arbitrary you can put origin anywhere we have put for our convenience at this point.

So, let us say I am not happy with this origin I have put the origin at this lattice point, but as I told you in the last statement here that I will still keep the my directions that science I am not going to change.

So, again my a is in this direction ok, positive a is like this positive b is like this and positive c is like this that is not changing origin has changed ok. So, now, I keep the same thing this is my origin. Now and now I see that where this particular plane is making an intercept ok. So, it makes an intercept in the negative direction of b. now in this case. it was making the intercept in the positive direction of the b.

So, when it makes in the negative direction now if I want to write again the intercepts. So, I will again write intercepts here first. So, it will be infinity minus one infinity and then I will take the reciprocal ok. So, it becomes 0 minus 1 0. So, my indexing will be 0 bar 1 0.

So, now, I we have seen for a negative 1 also if it is passing through the origin ok, it is convenient to just shift the origin sometimes you can also take a parallel plane, but for some plane finding out a parallel plane becomes a big headache you cannot do it easily.

So, passing shifting the origin but keeping the sense of the axis is much better way of finding out the intercepts let us take a little bit more complicated plane than this one to get more sense of finding out the indexing the idea is to find the indexing of some of the important planes of cubic crystal because that is what is going to come later on.

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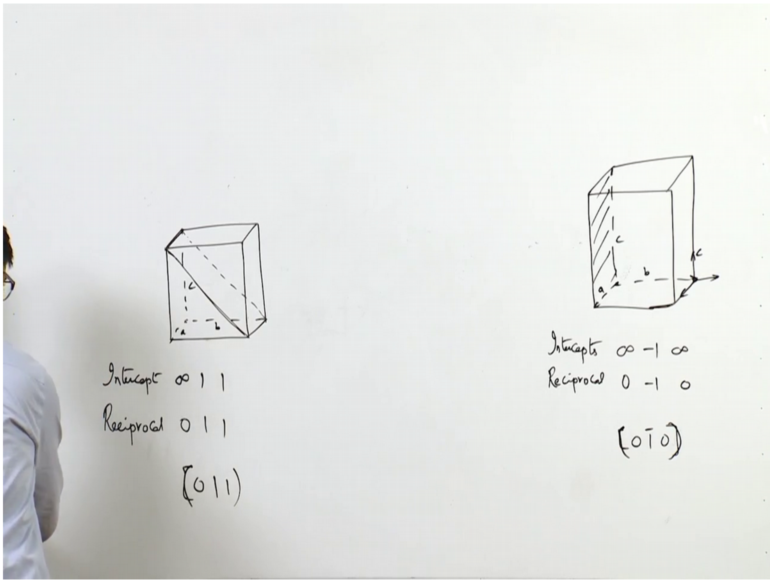

So, again this is my origin this is a, this is b, this is c, let us say, I am interested in a plane like this ok, it is going like this and the back phase also it is like this. So, this is the plane I am interested in ok, a diagonal plane like this.

Now, again find out the intercept. So, intercepts are it is again parallel to the a axis,. So, intercept at the a will be at infinity it has a intercept of 1 in the b. So, one intercept of 1 in c, again one again one again we will take the reciprocal of these values.

So, it will come 0 1 1 and then I will just write it in sorry I am writing it in the wrong way it should be parentheses it should be parentheses 0 1 1. So, earlier also I think I made a mistake of putting the, this indexing this should all be in parentheses please remember that. Now let us say we will go to a little bit more maybe where.

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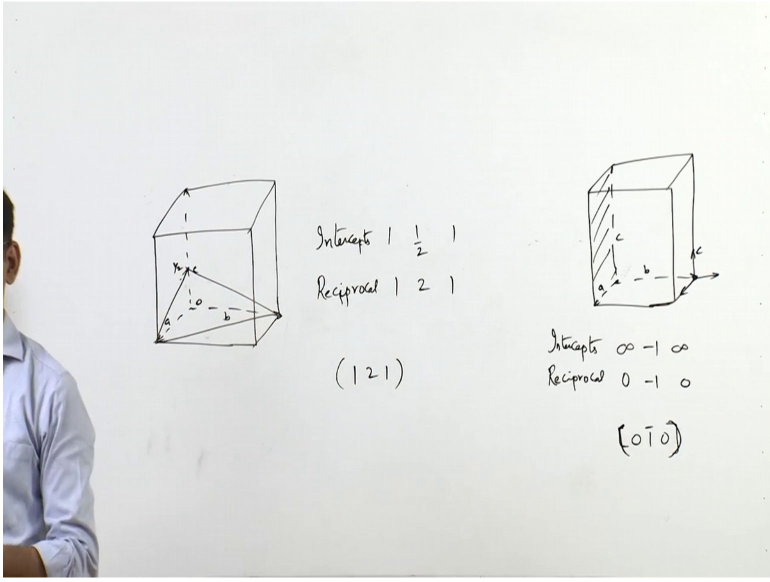

You are getting the fractions here again I will draw the and let us say the plane is something like this. So, this is my origin a b c and somewhere here this is the plane we are talking about.

So, it is cutting at some location half of the c and one unit one unit in a and p direction. So, again we will take the intercepts. So, intercepts will be one half and one and now I will take the reciprocal first this please remember we are not making integers at this moment first we will take the reciprocal, it will be 1 2 1 now it has already become integer.

So, we do not have to do anything I will just write it in parenthesis like this ok, you may sometime get a fraction such that you have some number here also. So, when you take the reciprocal you get some number in the in the denominator.

So, you just have to multiply by that common factor to get the integer values here. Now there is another concept which is which is given in the slide which is called family of planes ok. So, just see this concept family of directions and family of planes.

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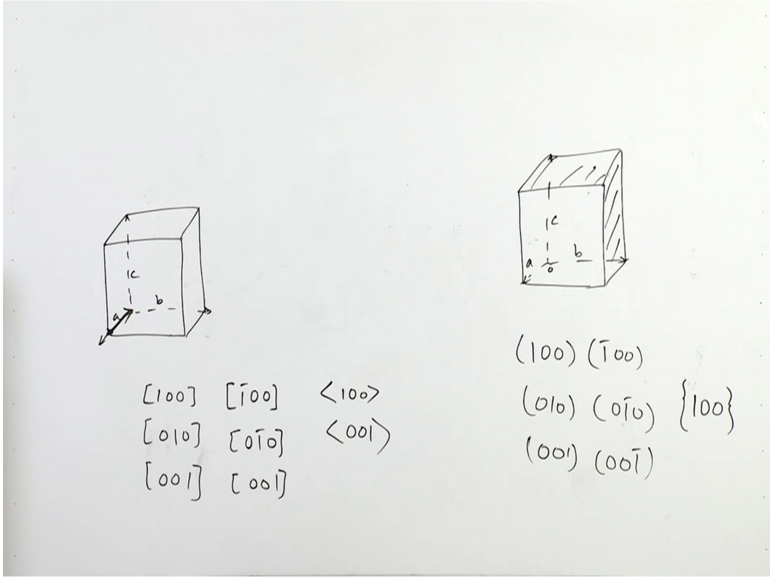

So, for example. So, we said this crystal x is a, b and c I have the in case of directions I have the indexing.

Like this 1 0 0 0 1 0 and 0 0 1. Now you can also have negative of this ok, suppose, I instead of going like this ok, I am going in the opposite direction, I am starting from here and ending here ok. So, I am going in a negative direction then this will be bar 1 0 0 0 bar 1 0. Now in terms of length of each of this vector these are all same vector they are a part of the same family. So, to represent this as was told in the first slide this particular slide that when you have this kind of family of direction I can represent this whole thing you I do not have to write every time all of them if I want to tell the family.

There I can just write it like this or maybe if you like this I can just write to it represent all the six directions which you have shown by a family. So, I have just have to put this places here and that will give me the family of direction ok, why we are interested in family of direction because if you see if I just change the orientation of this particular unit cell here 1 0 0 may become a 0 1 0 0 1 0 may become a 0 0 1 if I change the orientation of this. So, there is and if you see the properties.

Any properties along this direction for that particular property all all directions are same because there are inter atomic distance will be same in all these 3 directions. So, for for a property it does not matter whether it is 1 0 0, 0 1 0, all are same. So, I can just represent them by a family of directions. Similarly, in case of planes also we can represent a family of planes this a, b and c, these are all positive directions with the origin here again, let us say we talk about these particular planes or this particular plane they are all same.

Ah of similar type. So, I can put all these planes as 1 0 0, 0 1 0 0 0 1, negative of that and they are all family of planes and I can represent them by these curly phrases by writing it like this. So, they are all same they are inter atomic distances is same for all these planes.

And so, they are of similar type, if I take any other type of planes ok, then I again I have to find out that what will be the different planes of a family and I can represent them in a curly phrases again we will do some assignments on this which will clarify this whole concept more clearly.

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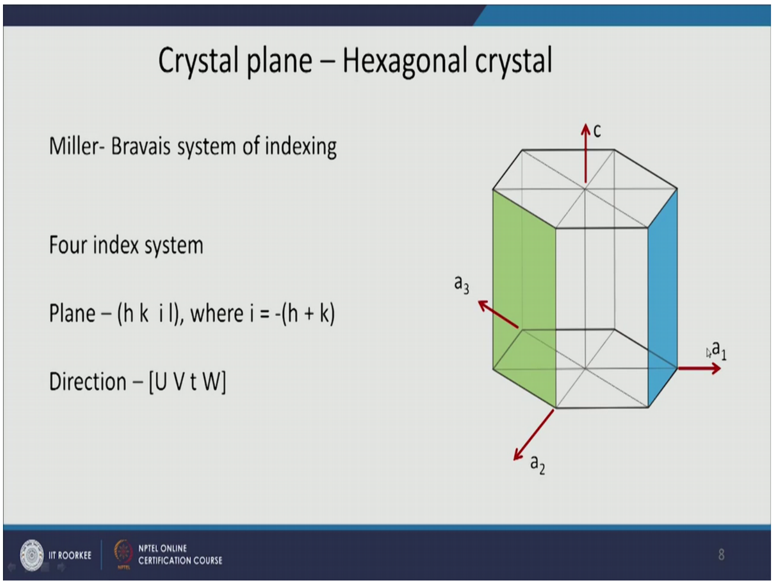

So, now, when we have a hexagonal system the story will be slightly different because we have now 4 axis for the crystal as you can see in this particular hexagonal crystal it is a 1 a 2 a 3 in the basal plane this is what we call as basal plane and the c is perpendicular to that and the indexing will be like this ah.

So, instead of the our Miller indexing system we follow Miller Bravais system of indexing which is a 4 index system. So, plane will be given as h k i l where I is also is related to h and k like this, I is equal to minus of h plus k and direction will be given by u v and there is additional t here and w. So, instead of following 3 indexing system we will follow the 4 index system.

In case of hexagonal crystal ok, now the question is why we want to do this kind of thing ok. So, let me explain this with a example here let us see we have all these planes here as you can see this green blue this white one and there are 3 in the back these are all prismatic planes.

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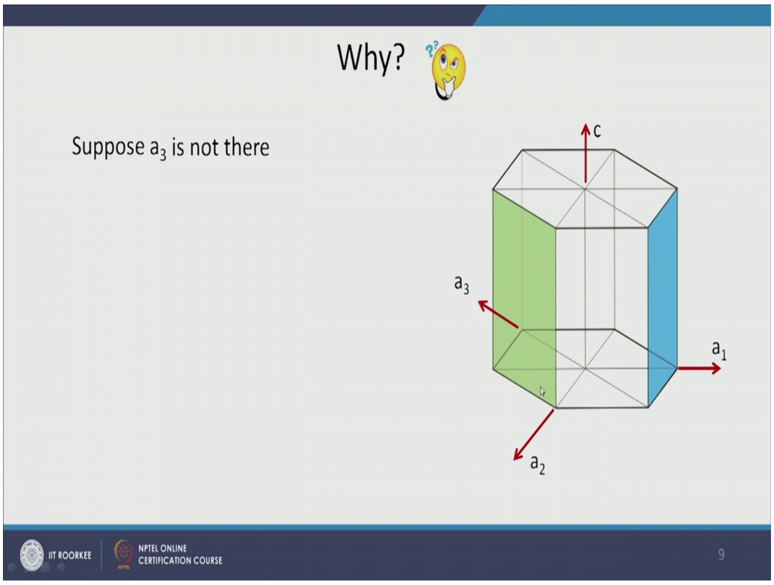

So, it is a hexagonal priest and these are all prismatic planes. So, let us see if you have we do not follow this Miller Bravais system, we will still follow the older the one which we have already discussed the Miller indexing system to index these particular planes here ok.

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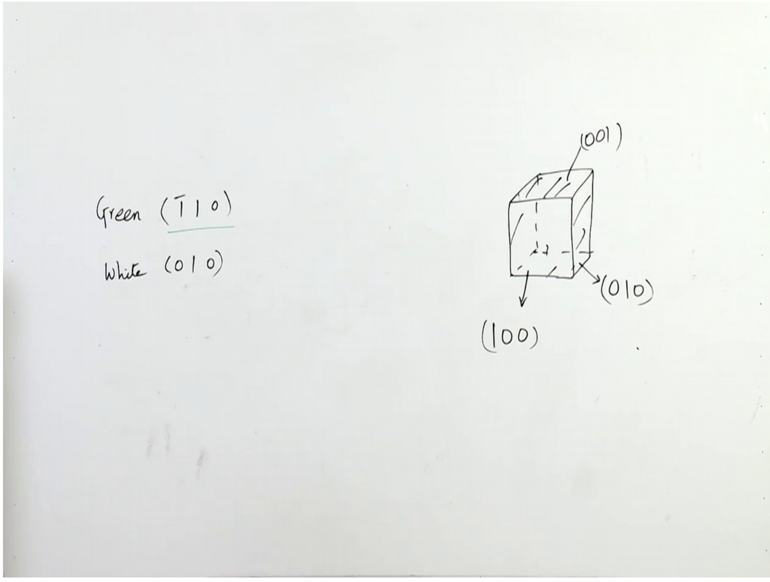

So, let say the green one if we want to see the green one will be bar 1 1 0 ok.

Because it is cutting the a a 1 axis in the negative direction as you can see here this is the origin in the negative direction it is cutting the a 2 in the positive unit direction. So, it will be bar 1 1 and it is parallel to ok. So, there is it is going to cut at infinity you taking reciprocal will give me the indexing is 0.

Now let us say, I want to now index this white one here ok. So, not the blue one let us say we want to index the white one here the front plane now what will be the indexing of this particular white plane if you see this plane it is parallel.

To the a1 direction and it is cutting the a 2, at this particular this particular point at one unit distance from the origin. So, now, the indexing for this particular plane will be it is parallel to 0 a 1 direction cutting a 2 at one and it is parallel to the c direction also ok.

So, now, if you see for one type of prismatic plane I am getting the indexing like this for another one I am getting the indexing is 0 1 0. Now, you compare this with the our cube one. So, this was also a prism a square prism and these are the prismatic plane in this case also and for all these planes this one this one this one the indexing.

Was looking very similar and for this one it was 1 0 0 this is one 0 0 or this is 0 1 0 and this is 0 0 1. So, there is no difference it will all look similar that is why we said it is a family of planes, but here also these all prismatic planes have the same should we have same indexing, but when I use the 3 indexing system.

They were showing different indexing; that means, there is some problem here and that problem can be rectified if I find out the intercept in all the 3 direction all the 4 direction to get an indexing ok. So, again we will follow the same principle of intercepts taking reciprocal finding out the integers and giving the indexing of that.

So, let us say we now take the 4 indexing system for this again same thing let say for green one.

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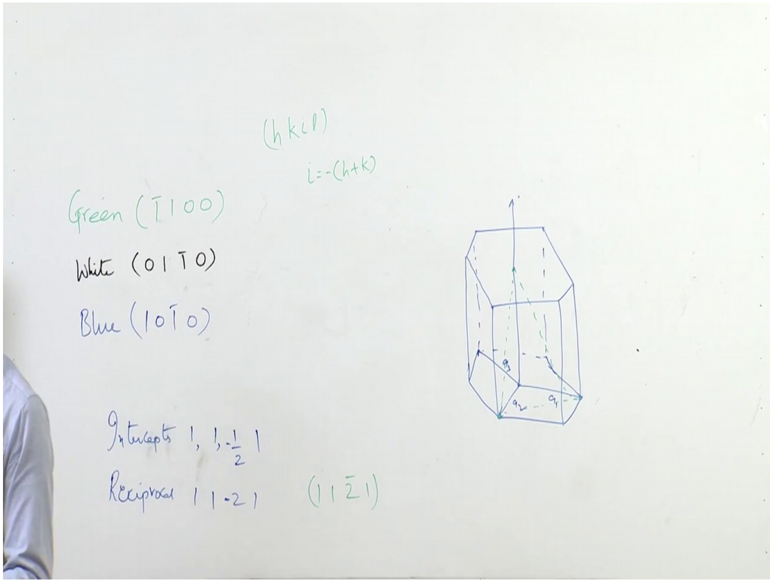

Let us say for the green one. Now now suppose a 3 is also there which was ignored last time and this is the green plane it is cutting a 2 a here a 1 at the negative, but now we will consider the third one also a 3 it is parallel to a 3, you can see this particular plane is parallel to a 3 and also parallel to c. So, for this one I will write it is bar 1 one 0 0 and you also remember that when I.

Said that we follow this h k i l in case of hexagonal we said that I also has some relationship with the h k like this. So, h is negative k is positive minus 1 plus 1 will be 0. So, I will be 0 and which is the case here. Now let us say about white one which we we had problem last time.

So, let us say white one here what will be the indexing now it is cutting a 2 here and it is cutting a 3 in the negative unit length here. So, now, in this case it will be and it is parallel to a 1 which we saw a last time also.

So, in a it will be 0 a 2 it will be one a 3 it will be negative one see again it is parallel to see, ok, again you can check whether this is followed here it is 0 k is 1 0 plus 1 1 minus of that it is coming negative here. So, we are still we are doing it correctly.

So, like that we can do for all prism and you will see all will have very similar indexing for example, the for the blue one also quickly I can do let us say for the blue 1 a 1 positive it is parallel to a 2 it is cutting a 3 negative direction and all look similar as you can see. So, now, there is no problem of.

Having different indexing for the same type of plane they all now look similar to to each other and that is why we follow the for indexing system ok. So, now, the the indexing remains same as we have already seen in the earlier case ok, if you want to draw different planes in the hexagonal system ok, you can do that for example, this you have to start drawing quickly. So, in this is how it is something like this and this is my c axis these are.

My a 1 a 2 a 3 this is a 1 a 2 a 3. So, suppose I am interested in a plane which is cutting a 2 here a 1 here and let us say it is making an intercept here. So, maybe something like this ok. So, we are interested in a plane like this ok.

Now let us see in a 1 it is cutting at the positive one may 2 also, it is cutting at positive one sorry I will first write the intercepts and then we will see what is happening. So, intercepts I am writing first 1 1, now it is also making an intercept for the a 3 axis.

And it is in the negative direction ok. So, if you do a little bit trigonometry here you will find out that it is cutting at half of a 3 ok. So, it will be half here and in c again it is making at one and now we take the reciprocal. So, it becomes 1 1 2 one sorry it is a negative this is negative. So, in terms of the how to write this in terms of our indexing system it will be 1 1 bar 2 and one. So, this is how I am going to write it any other plane we can take or we can take some plane in the assignments also to get hang of the indexing system for planes ah, now we will come to the.

Directions of hexagonal system and direction actually you will start getting some dizzy spells. So, you have to be careful when you are doing indexing of direction in hexagonal system and the reason is that again you have to do something you have to see some funny things which are happening here ok, for example, if you just follow the what we did in case of when we were using Miller indexing system.

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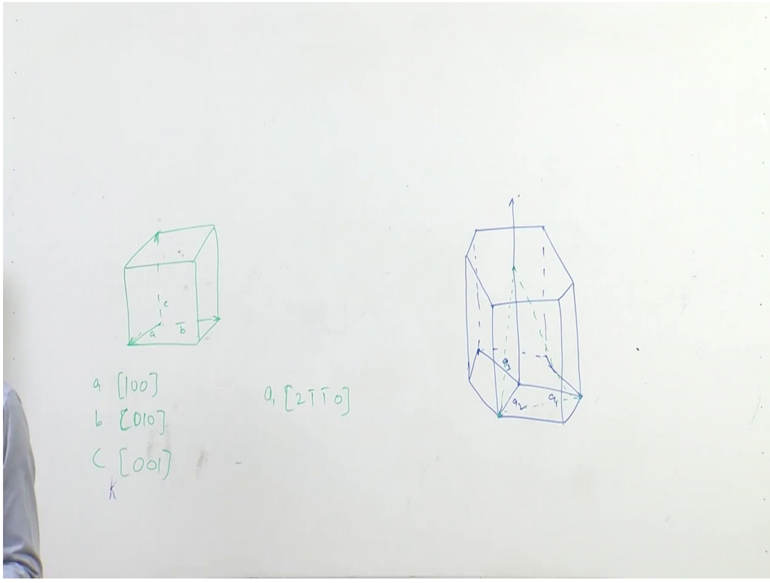

So, I am taking this cube again ok. So, this my primary crystal axis which were given like this where 1 0 0 for a to be it was 0 0 1 0 c, it was 0 0 1.

Now if you try to follow that same here it should be for a 1 it, it is one o o for a 2 it should be one 0 one o o and for a 3, it should be 0 0 1 0,, but it is not like that actually if you see in the for indexing system the a 1 is 2 bar 1 bar 1 0 that that is the indexing ; that means, I have to go 2 units along a 1 negative one unit along a 2 negative one unit along a 3 and then of course, I am not going into the c direction.

So, it will be 0 there. So, this is what this is the indexing we have to do, in case of hexagonal system to take care that we are going along all the 3 directions. Now if you just do it like this sometime it becomes very difficult ok. So, to simplify this whole idea actually you can convert between the 3 indexing system to 4 indexes system very easily and there are relations which are given here to do that. So, every time to find out that how to go in all these 3 or all in this 4 crystal axis and finding out the right indexing of the particular direction becomes little bit difficult.

So, what we do is we do it in 3 indexing system and then we convert it into 4 indexing system.

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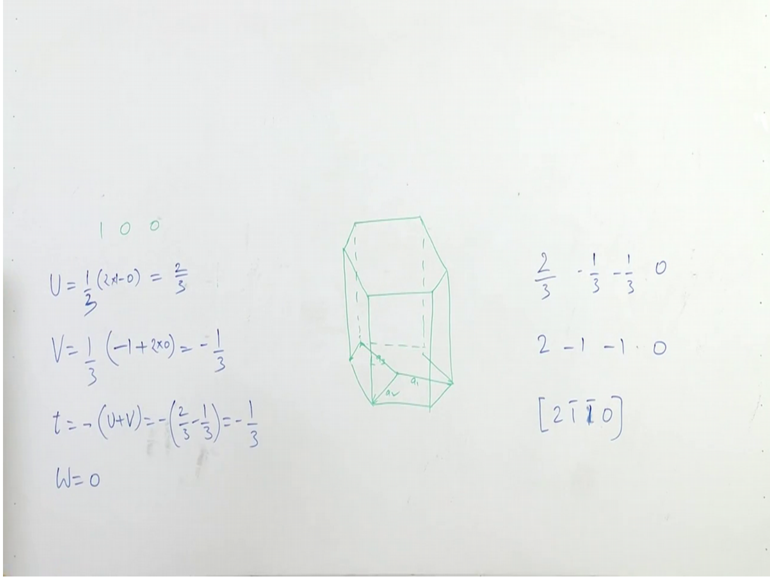

So, for example we will take the this primary direction itself as an example ok. So, let us see. So, this is my center, this is a 1 this is a 2, this is a 3 let us suppose we index a 1 using the worth 3 indexing system which we used for millers indexing system ok, sorry, a 3 I draw wrongly a 3 will go here. So, a 1 will be.

From that system it will be 1 0 0 the u v w will be 1 0 0 now let us use this conversion which is given here to find out that what will be in the 4 indexing system ok.

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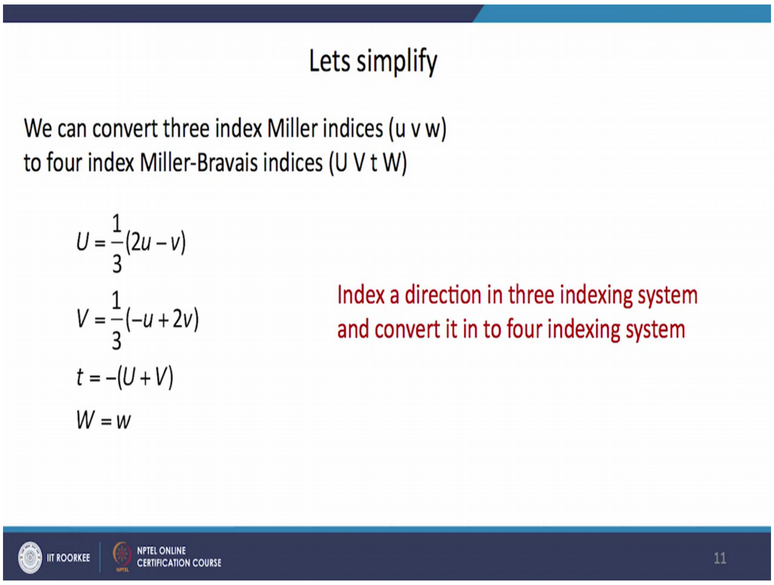

So, u will be equal to the 1 by 3 2 u minus v. So, 1 by 3 2 into 1 minus 0 ok, this is equal to 2 by 3 v will be equal to 1 by 3 2 v minus u is given there or I can write it as minus u plus 2 v whatever. So, it will be 0 minus u plus 2 v. So, it will be minus one plus 2 into 0 that will be equal to minus 1 by 3 t will be equal to whatever you are getting u and v here.

Negative of that. So, minus u plus v that is equal to minus of 2 plus 3 minus 1 by 3 here. So, that comes to minus 1 by 3 and w is w w is 0 because the last one is 0 here. So, this is coming as this my and 0.

And now I have to take the integer of this because it is in fractions. So, I will just take the integer values of this. So, it will come as 2 minus one minus one and 0 and which I can write as 2 bar 1 sorry bar 1 0. So, I think it is same as what we.

Said that the 0 1 0 0 the a 1 x is should be 2 bar 1 bar 1 0 and this you can do for any direction.

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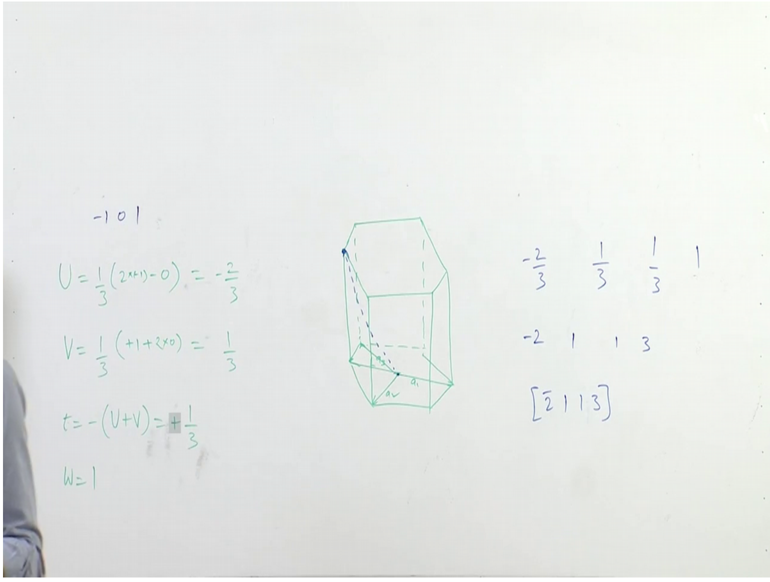

Now we can a take any direction may be let say we take a direction like this starting from here may be going there. So, if this is the direction we are talking about.

So, going for this direction what we will have to do I will have to this is my negative a 1 this is my negative a 1. So, for going to this direction I will be going in the negative a 1 direction and positive c direction can you see that negative a to c will give you get me to the end point of this particular direction.

So, in 3 indexing system I will write this particular s minus one nothing in 0 a 2. So, 0 and then see it is one ok. So, again we will do the calculation. So, u is 1 by 3 2 u minus v is 2 minus one minus 0 and that comes to minus 2 by 3 v is equal to again one by 3 it is minus u.

So, minus u is now become plus one plus 2 v 2 into 0 that comes to 1 by 3 t is minus of u plus v that is minus 2 by 3 plus 1 by 3 it will be 1 by 3 and w is equal to w. So, it will be one ok.

So, now again we can write it there. So, it is minus 2 by 3 1 by 3 1 by 3 and 1. So, now, again I will take the to take the integer I will multiply the whole thing by 3. So, it will become minus 2 1 1 and 3. So, this particular direction is part 2, 1 1 3 similarly I can find out the, let us say in this case because I went into only one direction let us say we want to find out a direction like this starting from here let us say it is going up to here.

So, now, for this one I will be to starting from going in a 1 direction then a 2 and then c. So, for this I will be going along this, then I will be going along this, then I will be going along this to get to the final point. So, this will be in 3 indexing system it will be positive in a 1 positive one.

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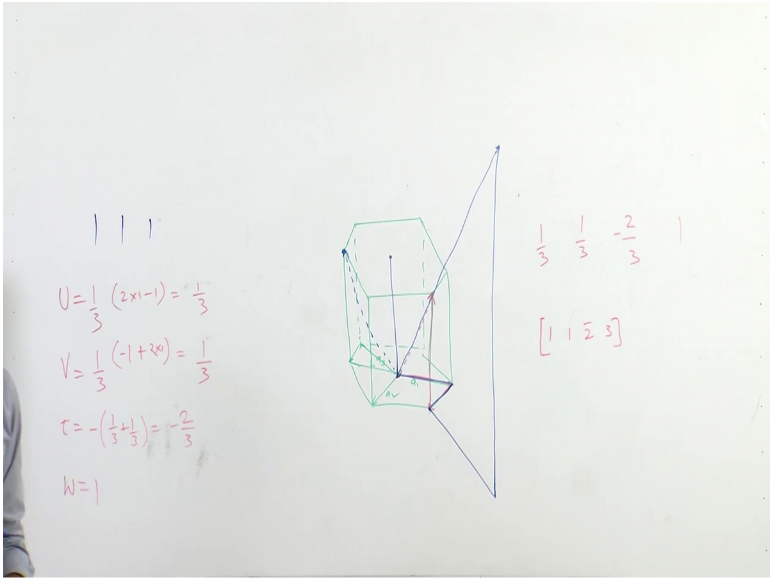

Then again a 2 positive one and in c, again it is positive one, let us see. Now find out our indexing for this u again 1 by 3 2 and u 1 minus v is equal to 1 by 3 v 1 by 3 it is minus of u plus I will write only 1 plus 2 into 1 will give you again 1 by 3 then t will be equal to minus of u plus v.

So, 1 by 3 plus 1 by 3 equal to minus of 2 by 3 and w will be one. So, let us write it there it is 1 by 3 1 by 3 minus 2 by 3 one again you multiply by 3 all over. So, it will be the indexing finally, will be 1 1 bar 2 3 now you may be wondering whether all these things we are.

Getting the right direction or not in actual terms because we are just keep on changing from 3 to 4 let us say suppose he actually want to find out this from this particular indexing which is given here ok. So, let say I have to go in one unit here.

So, I do it with blue right now. So, one in this then another one I have to go here then I have to go 2 negative in a 3. So, I am going 2 negative in a 3 ah. So, a 3 a positive is this direction. So, 2 negative of that will be ah.

Something like this and then I have to go 3 units in c direction. So, my c is like something like this ok. So, maybe I am going something like this in 3 units. So, if you see here I may be ending there this is my direction.

So, what I did in the 3 indexing system using our knowledge Miller indexing system using only a 1 a 2 and c I am able to convert that into 4 indexing system and I am getting that direction which we should have from what we have got here. So, this is working there is no problem here and we will again do ah.

Some assignments to get hang of the indexing method more example will give you a better idea. So, if the simplification is already done thank you very much I think it will be a a big lecture and if we understand that we will be able to do a good job of indexing plains and direction.

And you will start getting the picture or visualization of the when we say certain plane you will be able to immediately see which plane we are talking about ok, in case of cubic crystals or hexagonal crystal or if you say one direction you will be able to picturise which direction, we are talking about. So, once we have too many exercise to do the all this direction indexing and plane indexing you will be able to do that.

So, thank you very much for the, your patience.