Materials Science

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Lecture 13

Crystal Imperfections

In the last class we were talking about the point defects and we showed that they were in thermodynamic equilibrium and moved onto the line dislocations. And we saw edge dislocation, whenever any plane is not complete in the crystal, the internal edge of the plane forms an edge dislocation. Today I am going to talk more about this edge dislocation and try to generate a dislocation in a perfect crystal. But before I begin to do that, I just want to remind and give a caution that this is not the way anybody can create a dislocation in the crystal.

I am just trying to do something to convert a perfect crystal into an imperfect with an edge dislocation. Thereby I intend to define a few terms which we shall continue to use with respect to these dislocations. But keep it in mind the you cannot do these things to create a dislocation in the crystal.

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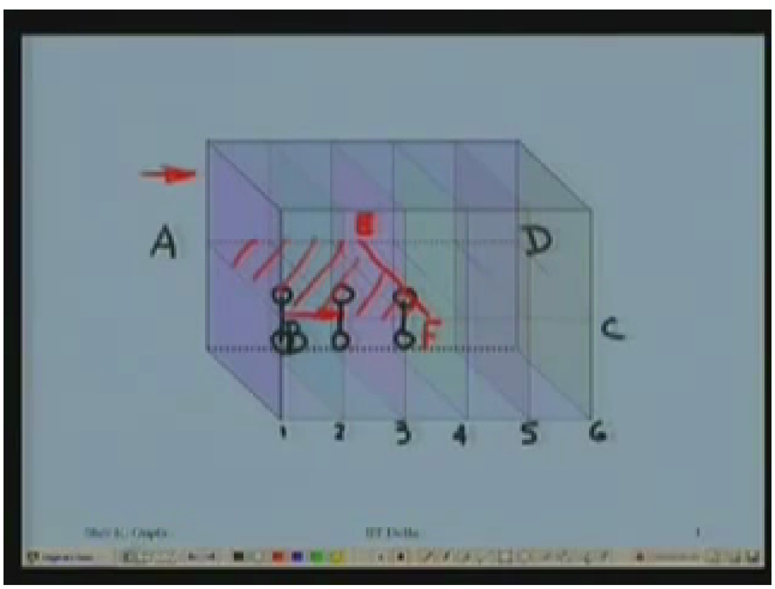

All right. Here I show a crystal where the vertical planes if you want you can number these. They are complete, go from top to the bottom. And this is let us say a simple cubic crystal. In the middle of the crystal I have sketched another plane, let me name this plane A, B, C, and D. All the planes, 1, 2, 3, 4, 5, 6, they are all complete from top to the bottom. And I have taken a plane, a horizontal plane in the middle of the crystal.

On this plane there are atoms above the plane, below the plane. Like this they are there and all of them and they are bonded like this. What I do now is for the atoms which are above the plane and below the plane, in between I break these bonds or cut these bonds in a certain region. Let us say that region in this place is, and name this as E and F. So A, B, F, E is the region on this plane A, B, C, D with a very thin narrow blade which is a fraction of angstrom thick.

Obviously you can see that you cannot have it. We cut all these bonds which are lying on this. So they will be on these three planes which I have shown there. These bonds are broken or cut. After I have done this, all the bonds are cut. Top part of the crystal I push with reference to the bottom part of the crystal with a force so that this first plane is shifted on this place by 1 inter planar spacing, by that much distance. I pushed it, pushed it hard. After I have done pushing, just introduce some glue in this region and allow the bonds to form again. All right. And see what happens when I do that.

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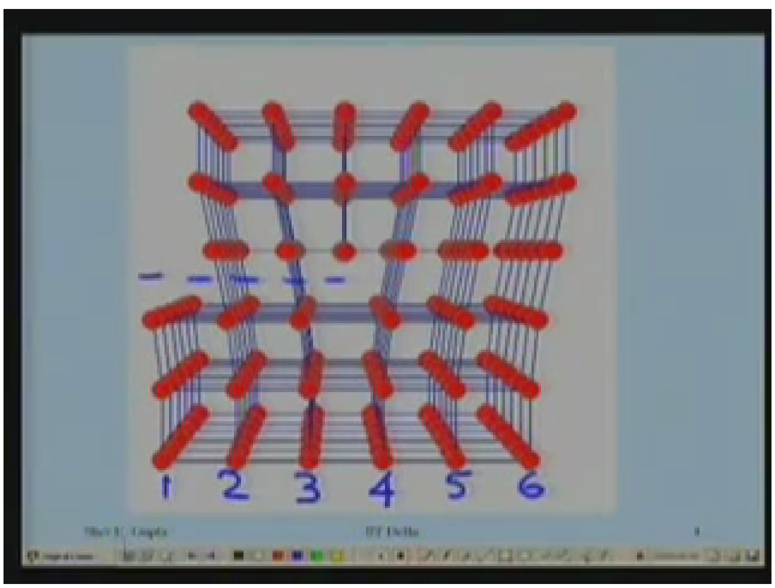

This is what happens when I allow these bonds to form. This is your plane number 1. This is number 2, this is number 3, 4, 5, and 6. And I cut the bonds between these three. So what has happened when I pushed this one on top? Number 1 has gone and bond with number 2 on the below this plane, this is a plane where I had cut the bonds. And this one got pushed to the third one. Number 2 got pushed from the top to the third one.

But third one does not get pushed to the fourth one because this bond is not cut. And therefore this plane ends here and is unable to form the bond there. I have formed a part plane in the crystal by this technique. All right. And this is the configuration of an edge dislocation. In here you can also see these bonds are compressed while this bond is extended. While I go away, the bond length becomes normal bond length. They go away, the bond lengths become normal but here these are compressed.

So above this plane where I cut the bonds, these are compressed and here they are extended. There is extension here, there is compression here. That is what we showed in the last class but this is what you see here. When I do this, that is done. By doing this what I have done is I have introduced a few things.

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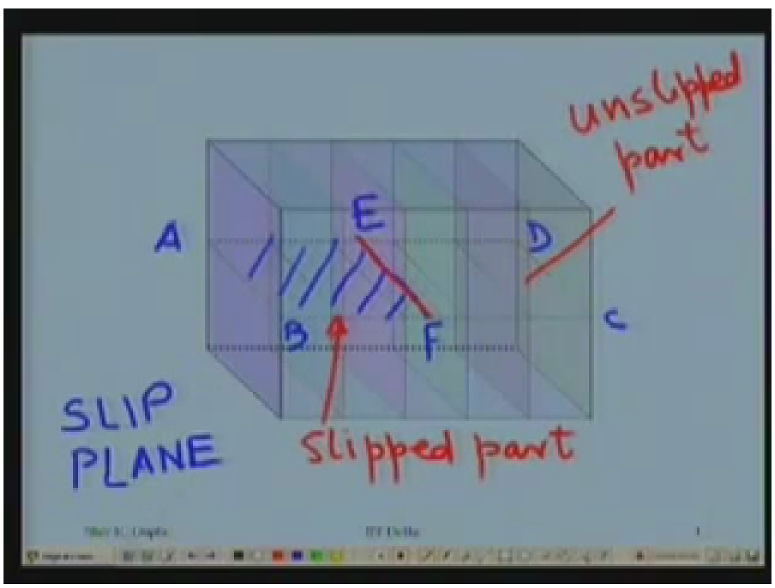

All right. What I have introduced is now the way I did things. I introduced this plane A, B, C and D. And on this plane you find this E and F. So this plane ABCD over which the crystal has slipped, I made it to slip. So I call this plane ABCD, the slip plane. On the slip plane, this part, A, B, F, E on which I pushed these atoms because I had cut the bonds earlier and then made the bonds again, I call it the slipped part of the crystal.

And this C, D, E, F is called unslipped part. But you notice that slip is a related term. If I call this as the unslipped and call the slipped that as the unslipped, somebody can call that as the slipped and this as the unslipped because this is the way I showed it is you cannot create a dislocation. It comes about in some other way. Those things we will see later. But these are related terms. Whether this part of the crystal has slipped with respect to that or this has slipped with respect to that? So the whole plane, slip plane has two parts. One is the slipped part, other is unslipped part.

And this line EF is boundary between the slipped part and the unslipped part. And what is this boundary? It is the edge of the part plane. And edge of the part plane is what I call the edge dislocation. So this EF is the dislocation. Where this line EF lies? It lies on the plane ABCD, as a slip plane. So these are some of the terms which I have introduced, right. And we shall now define a dislocation on the basis of what we have understood here.

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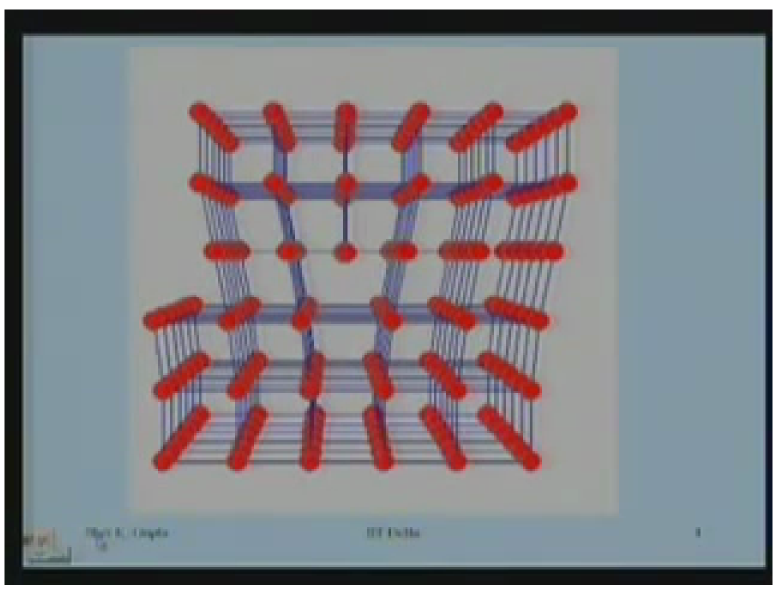

All that what you see, this is your……

“Professor-student conversation starts.”

Student: Sir, can you tell the, in the lower part why there is tension? There should not be anything.

Professor: Why is there tension?

Student: In the lower part.

Professor: See, this is why I said that I will first cut the bonds here. Push this one. So I am squeezing the top part anyway. Right, and allowing this form the bond with this and I have joined it with the glue or something. Let us say bond is formed. The bond is formed here. Notice here in this space I have more planes. And in this space I have less planes. Obviously that has to be adjusted. Squeeze the top part only. It is also relative. You can say that you have pushed the top to the right.

You can say that you have pushed, pulled the bottom to the left. So that way there is going to be a extension here. After all, the space is the same in which all these are arranged, all the 6 planes are arranged. Right. So therefore there is a compression here in this region and there is tension here in this region.

“Professor-student conversation ends.”

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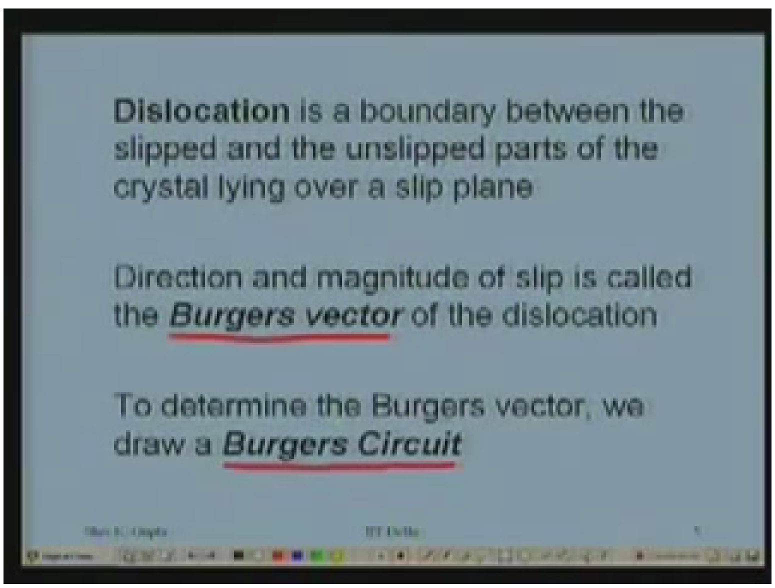

So I define now, a dislocation is a boundary between the slipped and the unslipped parts of the crystal, that we have seen and lying over the slip plane. I first created the slip plane. If the pushed top part of the crystal, this is first the bottom part, not over the entire plane, only part of the plane. So that forms a boundary between the slipped part and the unslipped part. And wherever the boundary is I got the edge dislocation. Is the meaning of the sentence clear to you? Good.

If the meaning of the slipped part, unslipped part and the boundary of these regions is clear, then I have to say about the extent of slip. While trying to create this dislocation, I said I will push the top part by one interplanar spacing so that my atoms of the first plane go to the second one in the bottom. Right. If that is clear, then direction and magnitude of this is called Burgers vector. Now as I said already direction is relative.

When I said top part is pushed to the right like this and bottom to the left, it is relative. So we determine the Burgers vector of a dislocation line by using a technique what is called drawing a Burgers circuit. Burgers circuit is nothing but a circuitous path in a crystal. Okay.

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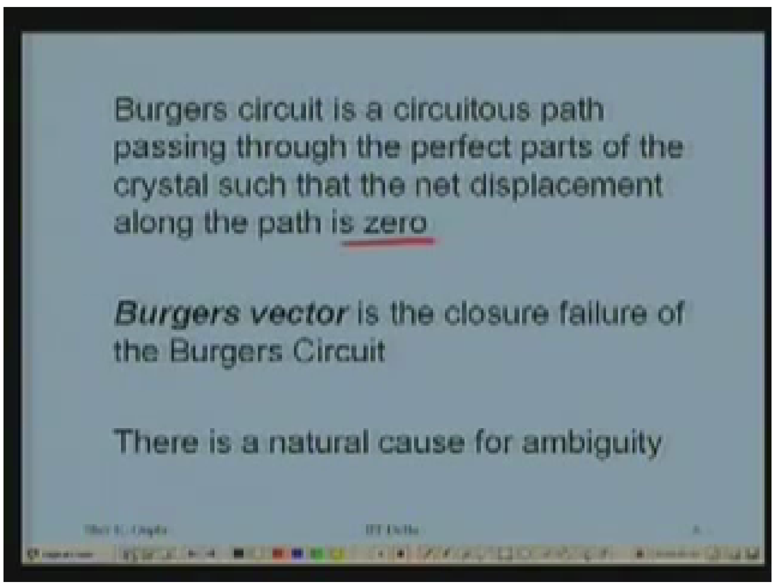

And this circuitous path passes through only the perfect parts of crystal, not through the imperfect. Imperfect path here I am referring to, I just showed you an edge dislocation, around that the bonds are strained. Above the slip plane they are in compression, below slip plane they are in tension, not through this region. Dislocation should, or the Burgers circuit should not pass through this region.

Perfect paths where the bonds are not strained, okay, so as to go away from this region. But it is a circuitous path and the net displacement along the path is 0. That is another important feature here, that the net displacement along the path is 0. We demonstrate that what I mean by this. The Burgers vector is then the closure failure or the Burgers circuit, we come back to there.

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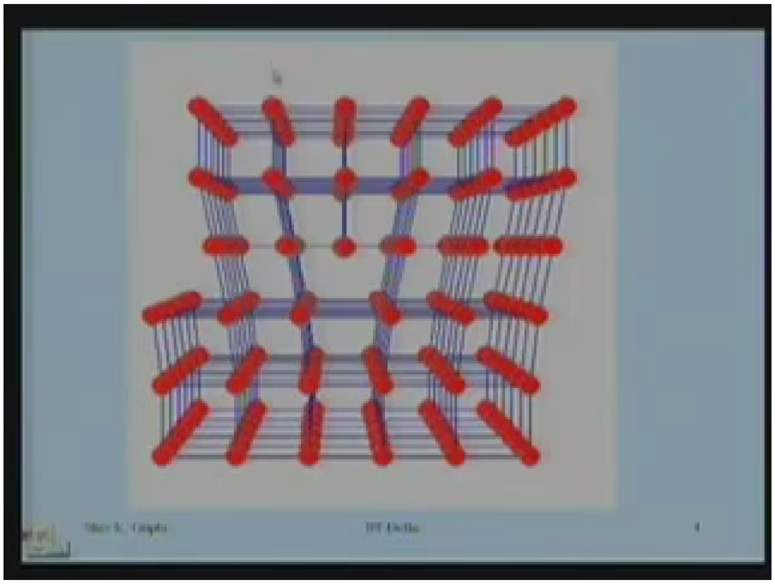

All right. This is the dislocated region here. And this part, let us say bonds are strained so much as I go away from this. So maybe I can start somewhere here let us say, sorry, to sketch a circuitous path. All right, before I do this, let us put a circuitous path in a perfect crystal. That would be better. Let us do that.

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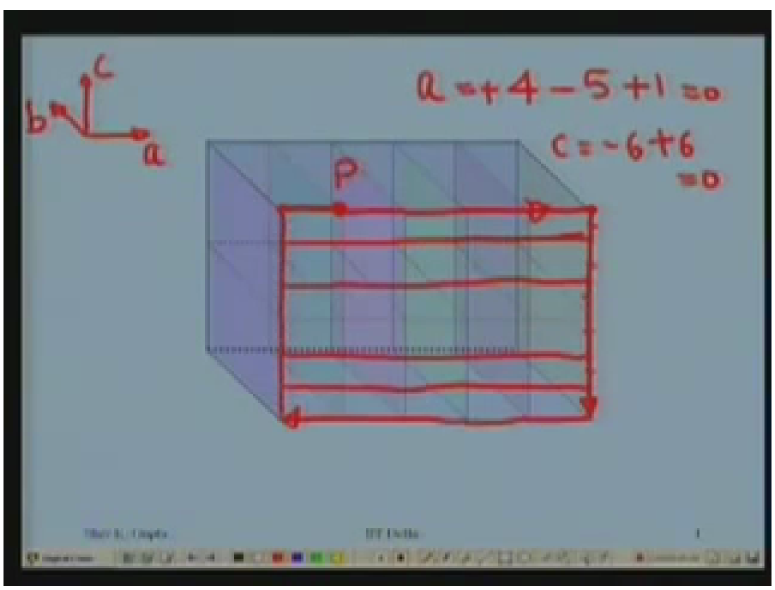

All right, is the one. In this, okay, let us try this. So I made it a, all the unit cells let us say. I start this point P and draw the circuitous path let us say I go clockwise, I reach at this point here. How much distance have I traveled? If I define my a axis and b axis, it will be easy for you to do that.

Let us define this as the a axis, that is the b axis and this is the c axis. How much distance have I traveled? I have traveled 1, 2, 3, 4, and this is positive of a. Right.

And let us travel this way. How much have I traveled now? 1, 2, 3, 4, 5 and 6. So I traveled on c, minus 6. I traveled here 1, 2, 3, 4, 5. I traveled minus 5 on a. All right. 1, 2, 3, 4, and reach here. I got plus 6 on c. That is still not closed. So I have to make it 0, I go here. We had plus 1, so I started P and ended at P, is the same point. Starting point, end point are the same. This is 0, this is 0, now my Burgers circuit is complete. So when I draw this in a perfect region, Burgers circuit has closed on itself because the net displacement of the path is 0. I will just show this now in my edge displacement what happens.

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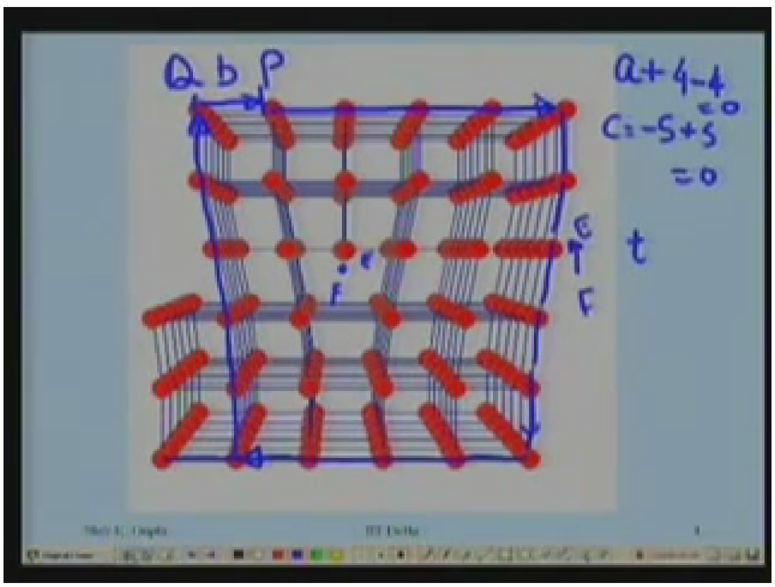

All right. Let us start at this point P. On a how much have I traveled? 1, 2, 3, 4. So I traveled 5, this is c let us say. I have traveled minus 5. So I traveled up to here. So let us go up to here only. Let us say this is 1, 2, 3, 4, minus 4 on a, so a is closed. 1, 2, 3, 4 and 5, plus 5, net displacement is already 0. Both a and c have become 0 but I end at Q. I started at P and ended at Q. Now the circuit has not closed despite the fact the displacement along the path is 0.

What I have to do is I have to add some more movement to make it closed. And that movement which I have to make is Q to P. So this is magnitude and displacement of direction becomes the vector which I call the Burgers vector or dislocation line. Right. This is the Burgers vector or dislocation line which we have found out. It gives me direction and magnitude both. This is the magnitude by which I had caused the displacement, caused the slip and this is direction in which I caused the slip. That you remember.

However this is what I did to the top part, displaced it to the right by 1 interplanar spacing. If my friend decides that I do not want to go clockwise, I would like to go anticlockwise, he starts at Q, goes along, makes the net displacement 0 and reaches at point P. And to close the circuit he will have to add P to Q, not Q to P. Magnitude is all right but the direction has changed. And this is obvious ambiguity. Why it is obvious?

There are two parts. One, above the slip plane, one below the slip plane. Top part is pushed to the right, other words bottom is again pulled to the left. Reference is what? Depending upon what is my reference if I have taken my bottom as reference, I found a displacement at the top, that is correct. If you take top as the reference, find out displacement of the bottom, you will get the opposite. So we settle this ambiguity once for all by saying that Burgers circuit is drawn using a right hand screw notation.

What is a right hand screw notation? For the right hand screw notation, the first thing is I must decide the direction of the dislocation line. In this case my dislocation line is right here going inside. F point, E point, they will be visible at just one point here, is a line inside the crystal. Okay. Front is F, and the back is E. So whether I take the direction of the dislocation line E to F, or F to E, it is arbitrary and left to me, left to the user.

You can choose the dislocation, it is a line. Dislocation is a line. Nobody has shown it as a vector in the crystal. Direction once you give to it, it becomes a vector. That is called the dislocation line vector. So let us take from F to E. So if I take it from F to E, that is going inside like this, a dislocation line which we represent by a vector t let us say which is where, just a point here, this F to E. Then the right hand screw should be moving in, I should rotate this or the direct orientation of the Burgers circuit should be such that right hand screw goes in the direction of the dislocation line.

Right hand screw will go from F to E if I go clockwise. If I go anticlockwise, it will come from E to F. So right hand screw notation says I must have the orientation of the circuit such a way that if a right hand screw is rotated in that orientation it will go in the direction of the dislocation line. In my case dislocation line is going from front to the back because I have taken a direction F to

E. Is that clear? All right. So I must draw a clockwise circuit, then this is my Burgers vector. That I am finding out what is the displacement given the top part with reference to the bottom part. Is this clear? All right.

“Professor-student conversation starts.”

Student: In the direction of the Burger vector will be determined by the choice of that edge dislocation vector?

Professor: t vector, yes. It will depend upon that obviously then. We shall see that what it results in actually.

“Professor-student conversation ends.”

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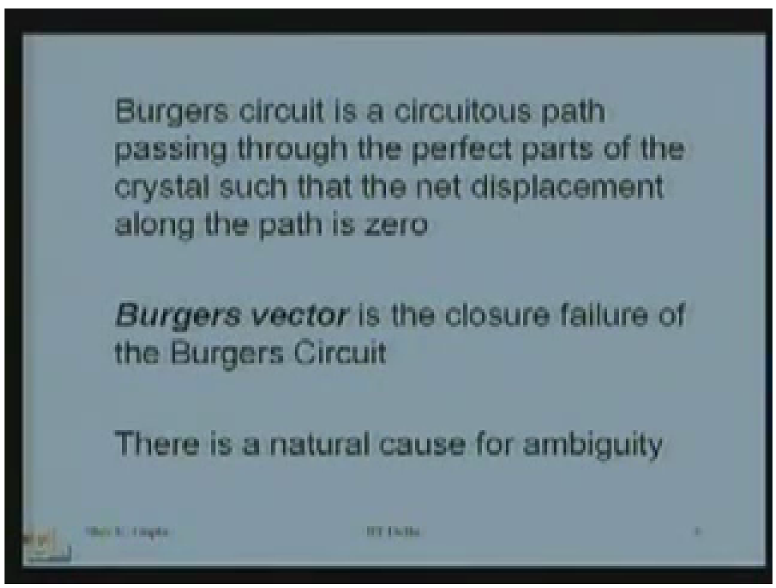

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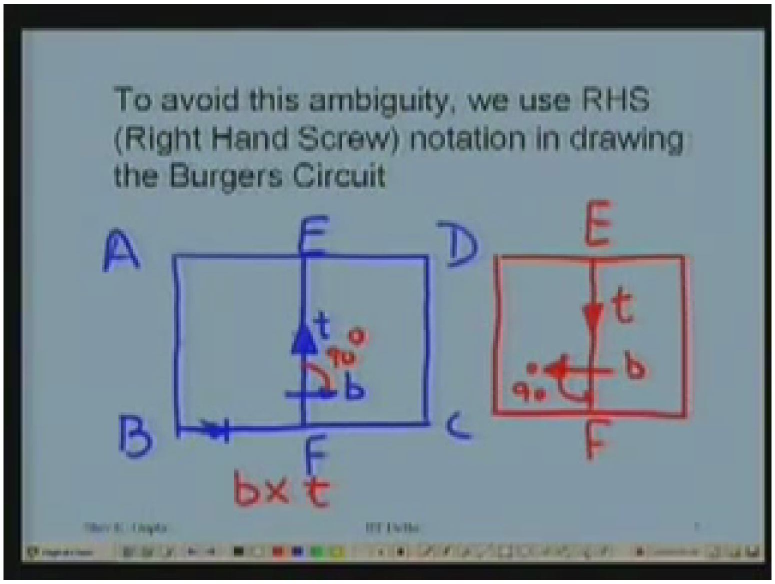

So we were here, Burgers vector is the closure failure or the Burgers circuit and there is a natural cause for ambiguity as we discussed. Right? And to avoid this ambiguity, we use the right hand screw notation in drawing the Burgers circuit. That is what I explained just now. Then I have no ambiguity. All right. Let us see what it results in. I had taken let us say this is my slip plane. All right. We have chosen the direction. I am sorry, I can make. I think we chose direction F to E. Okay. So this should be written off. This is my t vector. And we found the Burgers vector from Q to P like this. All parallel vectors wherever you draw, the same name we give them. This is the Burgers vector we find.

"Professor-student conversation starts."

Professor: Let me ask a question, if this is I had chosen the direction of the dislocation line, which way shall you draw the Burgers circuit?

Student: Anticlockwise.

Professor: Anticlockwise. The front plane you drawing, what will be the Burgers vector?

Student: Opposite.

Professor: Opposite to this. From P to Q, instead of Q to P. I say whether you have chosen the direction of the dislocation line F to E or E to F, you have got the consistent result. What is the consistency here? Angle between b and t, that is b to t is 90 degrees. Define the angle like this. From b to t, the angle you define is 90 degrees. And if you look at the vector, if I talk in Cartesian geometry, let us say this is a simple cubic system where I can talk of the Cartesian geometry. Look at the vector b cross t, which way does it point?

Student: (())(31:15).

Professor: Out of this plane but in the crystal, this plane is the slip plane. Which way it is pointing in the crystal?

Student: I cannot receive it.

Professor: Above the slip plane ABCD, it points above the slip plane and that is the site where I have the part plane. Now the dislocation is on the slip plane, it points in the direction in which I have the part plane whether I take this or I take that. That is why I mean, when I say this, I say this result is self-consistent. So it is a material which direction you choose for the dislocation line. Is this clear? Whether you take from E to F or from F to E, it is left to you but you must draw the Burgers circuit using the right hand screw notation. Then you will get the right kind of Burgers vector.

“Professor-student conversation ends.”

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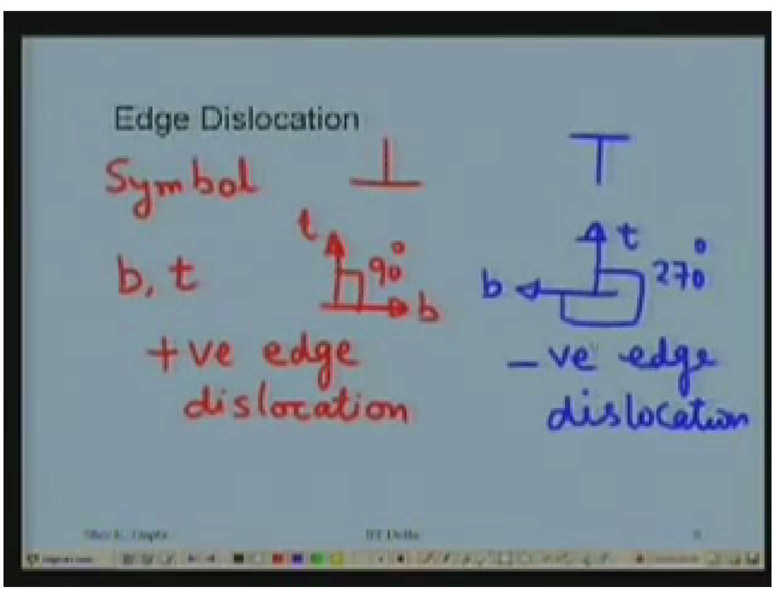

Now in the edge dislocation which we have shown the symbol I use to represent this dislocation which I just showed you, the part plane coming from the top and there is a slip plane at the bottom on which it stops. It is an inverted T basically. So this is the part plane and this is the slip plane. As a symbol we use and in here we have seen the relationship between b and t, angle is 90 degrees. This is b, this is t and this angle is 90 degrees.

b cross t points upwards, so relationship between b and t, such a dislocation is called positive edge dislocation. This case I get the push to the top part to the right, instead I had given the push to the left part to the right. Sorry, the bottom part to the right, instead of top part to the right I had given push to the bottom part to the right.

“Professor-student conversation starts.”

Professor: Another words, I had pulled the top part to the left, what would have happened?

Student: There will be (())(34:30) in the plane.

Professor: No, what would happen to the structure when I do that? Where would the part plane be if I do that?

Student: Below the slip plane.

Professor: Below the slip plane, we understood this. The part plane would be below the slip plane if you do that. That means the whole configuration is upside down.

Student: Yes.

Professor: Configuration would become upside down. Part plane is below the slip plane. In such a situation we write the symbol like this. This is the part plane coming from the bottom and stopping at the slip plane. In this case when you find out b and t, if you take the t vector like this going inside the crystal, you will get the b vector like that. Angle between b to t will be you will find 270 degrees, not 90 degrees.

“Professor-student conversation ends.”

I am working out from b to t. All right. And this is called a negative edge dislocation. Now why there is a need for me to call something positive, something negative? Because when I turn it upside down, it has become positive. Negative, it was negative, it become positive. But the positive would become negative. Because any crystal I could have two things existing together, one with the configuration such that the slip plane, part plane is coming from the top. The other one is there with the slip plane here and the part plane is coming from the bottom.

They are existing together. Strains in one are positive of the strains in the other. Therefore why is a need for me to call one as positive, other as negative? More we shall understand when we start to see when the dislocations begin to move, they come together, come towards each other, go away from each other, what happens. We will come to there when we talk about it.

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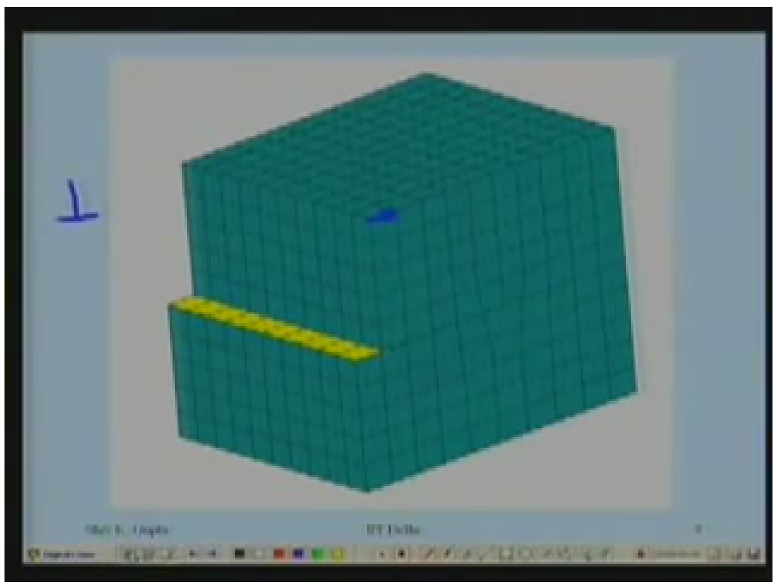

Right. Now this is I have shown one three-dimensional crystal, solid crystal, simple cubic again. The configuration of a dislocation, edge dislocation. This is that part plane which stops here and this is a, as shown here is a positive edge dislocation, is coming from the top and stopping at the (part) slip plane which I shaded yellow here as the slip plane. Right. And see number of planes at the top, number of planes at the bottom are the same, they are not different. But in here they are the same number of atoms are squeezed in this one planar spacing less. That is why you see these are in compression while these are in tension.

"Professor-student conversation starts."

Student: Are the number of planes same in that?

Professor: Yeah, you can see that. I started the perfect crystal, cut the bonds here, slip the top part to the right, now I got the configuration. If I allow it to come forward, push it, maybe this goes out and then becomes a perfect crystal. See, number of planes you can count, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11. Count here also. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, is the same, it is not different. Is this clear?

“Professor-student conversation ends.”

That is an edge dislocation in the crystal. And you can draw the Burgers circuit, you will find the Burgers vector turns out to be equal to this push which we have given here.

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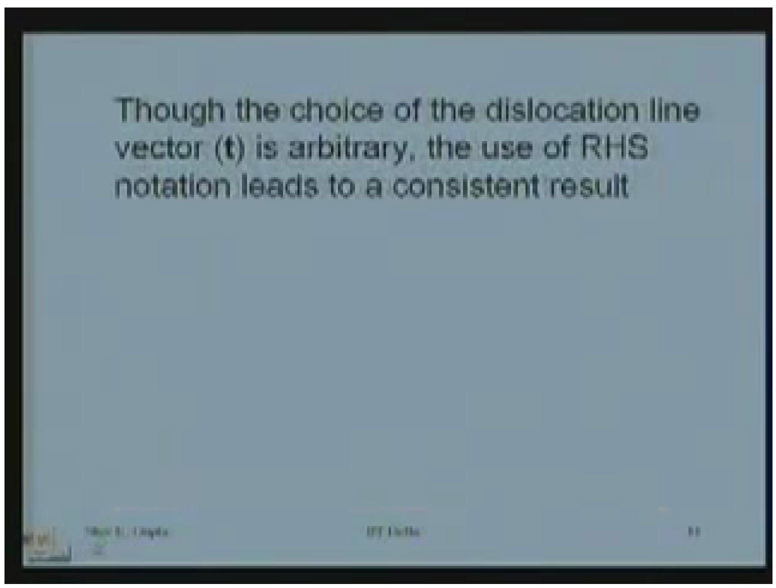

That is what I just now explained that though the choice of the dislocation line vector t is arbitrary, you take it from E to F or you take it from F to E, this notation, right hand screw notation leads to a consistent result.

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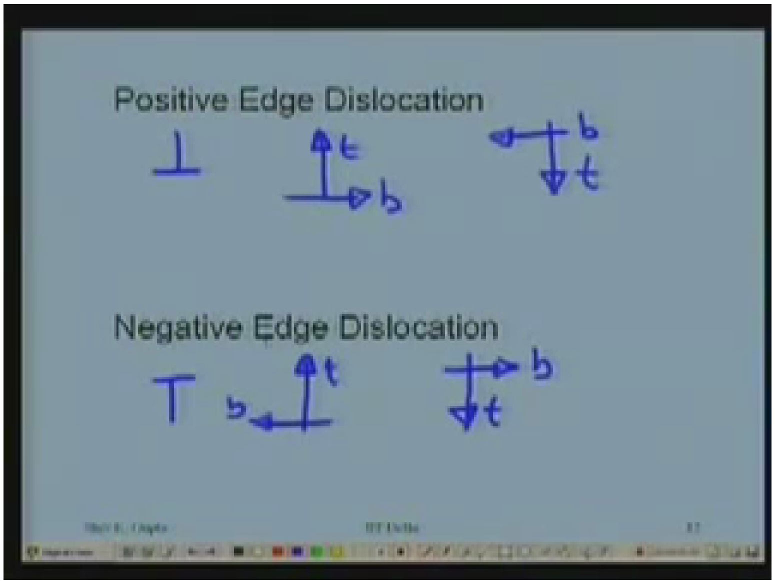

While I just now explained this positive edge dislocation and the negative edge dislocation, is the positive one. t and b or you can have t like this, then the b will be like this. Negative edge dislocation is this where t is this way, b is this way. Or you can take the t this way, then the b would be this way. All right. That is the angular relationship between b and t. And this is as I said the Burgers vector is an important characteristic of a dislocation line. Particularly in edge dislocation line, Burgers vector is at 90 degrees to the dislocation line. 270 is also 90 perpendicular. So Burgers vector is perpendicular to the dislocation line. That is an important characteristic of the edge dislocation. Okay.

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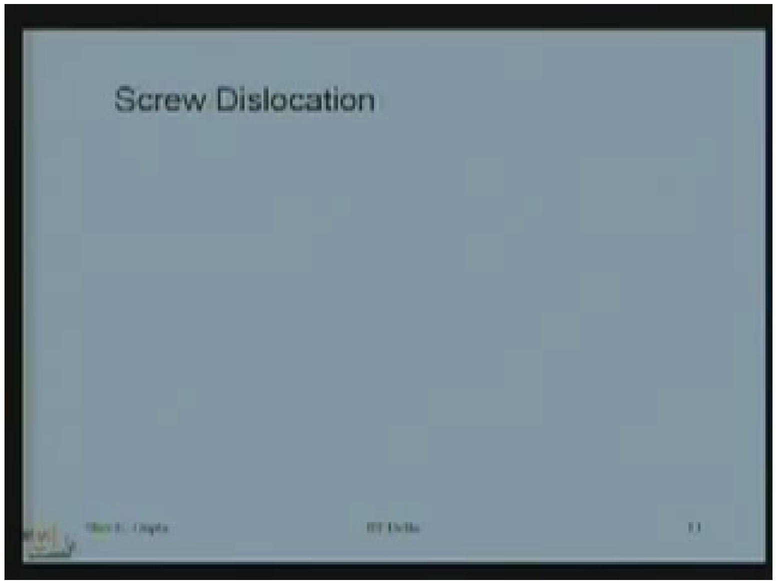

Next probably we will try to see the another straight line dislocation which is a screw dislocation. This is another straight line dislocation, okay.

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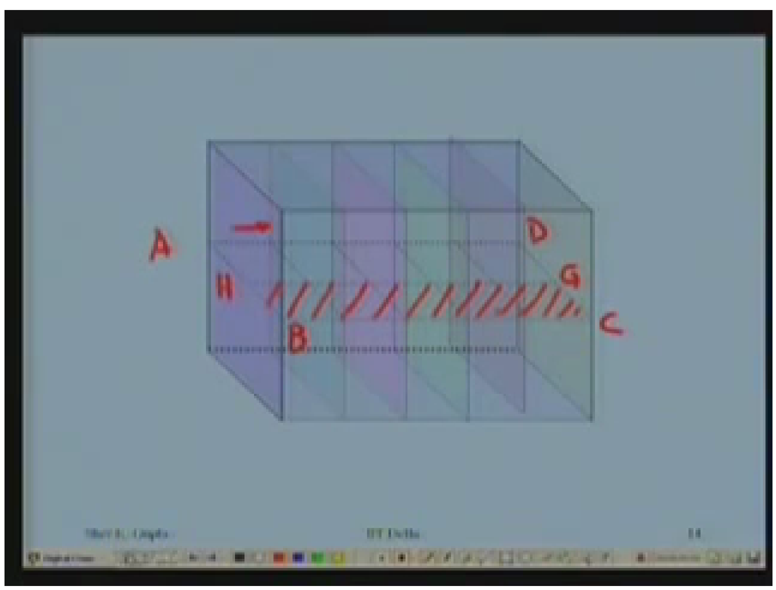

All right. Let us come back to our perfect crystal with the vertical planes shown there. Now what I do is on the slip plane which I named ABCD, let us make the slip which I said, I will cut the bonds cross, name this as G and H. Let us cut the bonds on this slip now, on this part of the plane, that is BCGH. This we cut the bonds, give the top part again a push by one interplanar spacing but in front, the back since you have not cut the bonds, you will not be able to do it but in front you can do it.

Push them so that this atom which is bonded here will go and bond with that. Okay. Like that it will go on and once you have done this push, let us see what happens to the configuration after give this push and allow the bond to form again, what happens.

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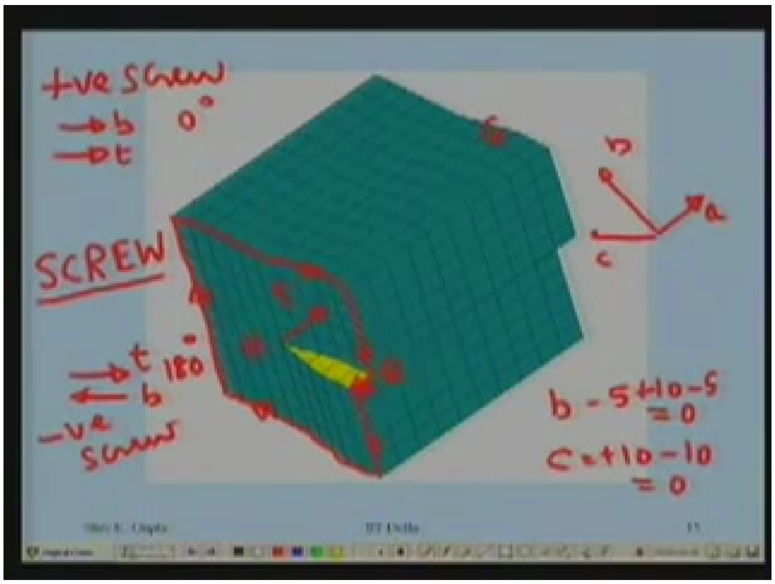

We get a configuration like this. I tilted it to show you what is going to happen here. It is up to here I have cut these bonds, beyond that bonds are not cut. So this atom on here is bonded to that atom without problem. But this bond is cut, so this is pushed but cannot be pushed as much as front one can be pushed. So I have been able to push this by almost one interplanar spacing. All these go for fractional distance because this one does not move at all because bond is not cut there. So some kind of shear is taking place in the crystal.

"Professor-student conversation starts."

Student: Within this case the edge dislocation will enter because we have not, we had cut through the plane.

Professor: Yeah, yeah. You cut this, there is no edge here. While what I am going to show what it is, there you will see that. So this is the configuration which I have got. This has got bonded with the next and like that. And you notice here, you do not see any problem with the crystal, it is a perfect crystal. Every unit cell is a square, no distortions. Distortions are only here in this part.

"Professor-student conversation ends."

But if I look at here, each one of them is a square but maybe it is slightly tilted with reference to these squares. This is some kind of a shear has taken place here and a shear has taken place in this region. As I go away, these strains will also not be visible. There I have shown it purposely here just to demonstrate that something is happening. But when I go away some 10, 20 planes, I will not see those strains.

It depends also upon the nature of the bond. If natural of the bond is very flexible, very metallic kind of a bond, it may go beyond 10 planar spacings. But if it is a partial covalency is present, then it will not go very far off. So these strains do not go away very far but they are visible around here very much. Now let us see what has happened? After giving this push, the border or the dislocation line is here, this is the H point and G point is on the other side. That is the dislocation line.

But around the dislocation line what has happened? Just see that I start from here this corner, top left corner in the front and go backwards inside the crystal and then come down, move like this, I have come here and I try to move, well this is continue, I am going out to some other plane. Not on, I started here, I will never reach there. In other words, if you start from here, go in a clockwise fashion, I went in anticlockwise fashion. Go in the clockwise fashion, you start here, go in the plane below, reach here, come there, reach here, go to the second plane there, reach here, go there, go to the third plane there, reach here.

So you are able to go inside the crystal. But you try to do this here, you keep moving on the same place. Do it here, you do it here, do it there. These are called the perfect parts of the crystal. And if you are in the perfect, well here if you do, no problem, you will be there only. You shall keep moving on this plane only. But only when you enclose this region which is the GH line in your movement, but you are able to go inside the crystal as if you are going on the spiral stairs.

Now you have seen these stairs, this kind of spiral stairs in IIT are there, number of places. Go like this, going along the central line. So that is why it is called a screw dislocation. And like the clockwise or anticlockwise motion of the screw, it is either going inside the crystal or going outside the crystal. That is why it is called a screw dislocation. All right. Let me take my dislocation line is from G point it is going inwards to H, H is somewhere there let us say. It is going in. All right. I am sorry, I think I earlier wrote G on the other side, all right, let us rub this off. I wrote G on this point and H on this side. So my t vector is from H to G, that is my t vector.

"Professor-student conversation starts."

Professor: With this t vector which way should my Burgers circuit be drawn, clockwise or anticlockwise so that right hand screw notation moves inwards?

Student: Clockwise.

Professor: Clockwise. So let us start in this plane at this point P. Right. Once again let us define our direction vectors, let me draw parallel to this crystal itself. Let us call this is a axis, this is my b axis and that is my c axis. b is slightly tilted, it does not matter. We know what it is. So I go in this direction, this direction is b and how much have I traveled in b? 1, 2, 3, 4, and 5. Then you can go. How much have I traveled here?

Student: 10.

Professor: 10. And this is c. I have this my direction, okay, or motion. How much is this? 1, 2, 3, 4, 5, 6, 9, 10, again. Okay. And this is the direction b, so this is plus 10. All right. How much is that? 1, 2, 3, 4, 5, 6, 10, again, minus of 10. 1, 2, 3, 4, 5, it is minus of 5. b is 0, c is 0 and that is my end point Q. Burgers vector is Q to P. So I got the t vector like this and I got the b vector like this. See there are parallel.

Student: Antiparallel.

Professor: Direction is opposite, antiparallel, he is right. So t and b are facing opposite but they are parallel. That is the characteristic of the screw dislocation that b vector and the t vector are parallel to each other. In this case the angle is 180 degrees while the point in the same direction it is 0 degrees. Likewise where they point the same direction, I call them positive screw. And they are opposite like this, I call them negative screw. So this picture is that of a negative screw dislocation.

In positive screw, b and t would point in the same direction. Angle between them is 0 degrees, angle here is 180 degrees. So relationship between b and t, I have talked about, 0 degrees, 90 degrees, 180 degrees and 270 degrees. 360 degrees again is 0 degrees. And this give me the straight line dislocations, screw dislocations and the edge dislocation. Right.

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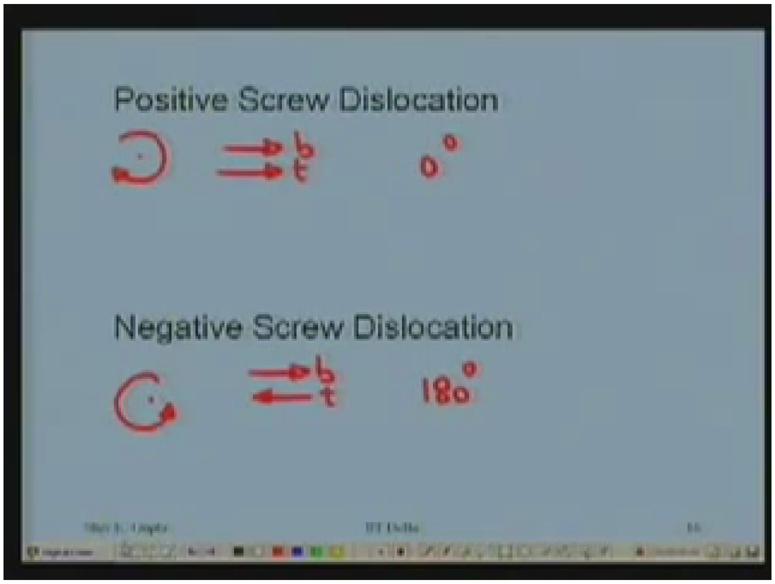

Then the dislocations in the crystal, well just to explain that, the symbol of course I have not explained symbol we use for. Positive screw, we use the symbol as a dot and surrounding this a clockwise circuit. That is the symbol we use for positive screw and in here b and t are parallel. Similarly in negative screw, the symbol we use is anticlockwise circuit and b and t are antiparallel. This angle is 0 degrees, this angle is 180 degrees.

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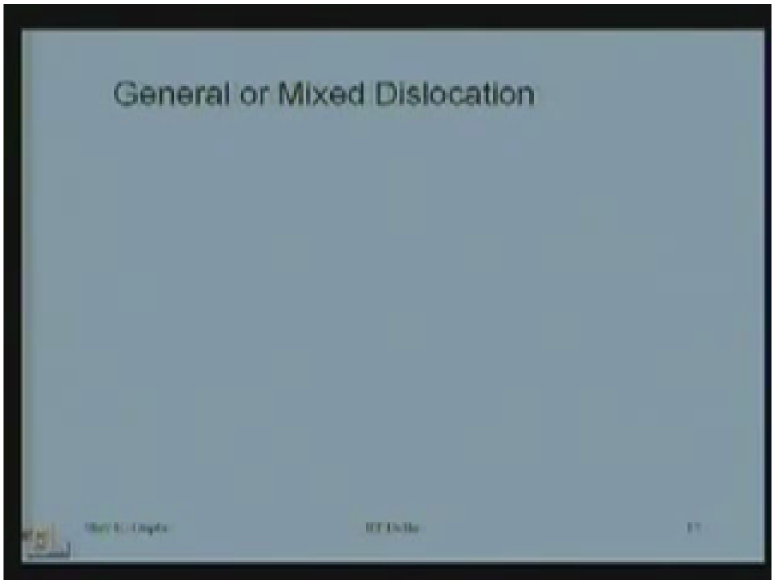

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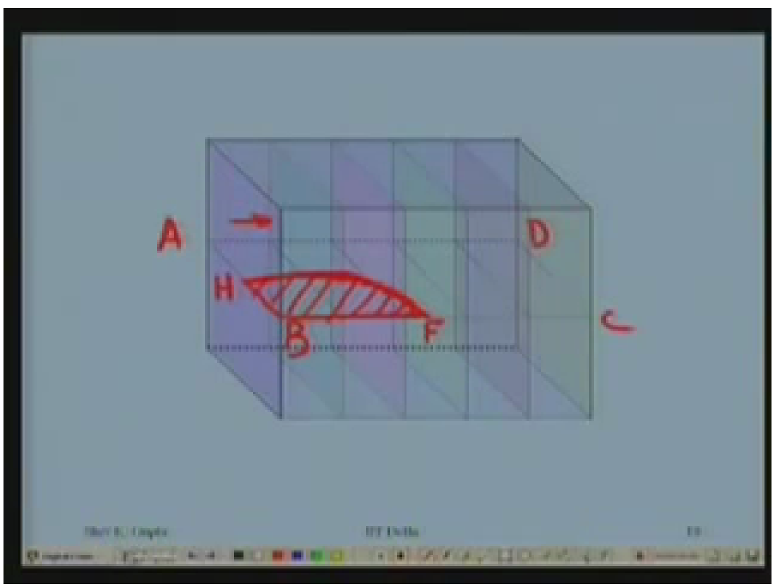

Now let us look at the general or the mixed dislocation. Okay. All right, I come back to my perfect crystal, simple cubic perfect crystal. And this is my slip plane, ABCD. Now I cut the bonds in this area of the plane. And let us name this as this was F point, do you remember? And this is my H point. Some curved path inside and I cut the bonds like that up to there and then give the front part a push again or one interplanar spacing. The configuration after doing this what you will get is this is the boundary, this is the dislocation line.

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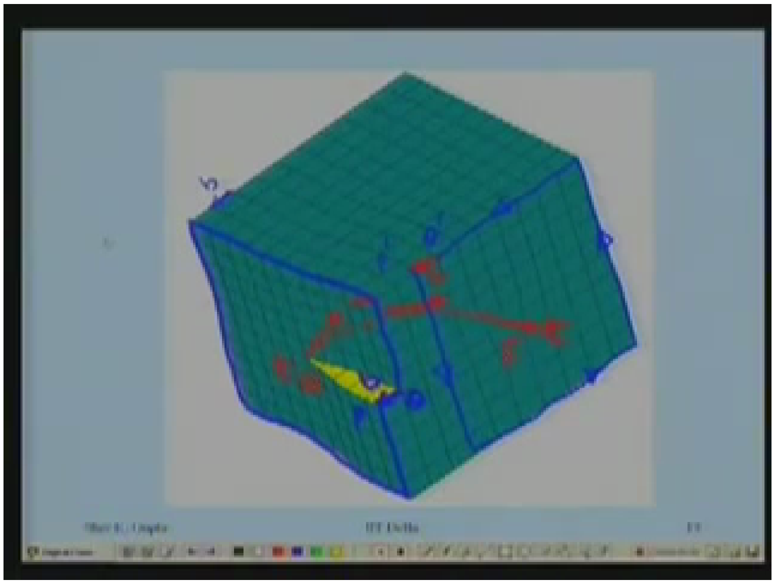

What you would get is this. This is cut pushed but is not able to get pushed beyond this like in the screw we saw. But here you get a part plane. So configuration here is that of a screw, configuration here is that of an edge. But in between you will find the mixed component now. Very important thing is here, all right. So my dislocation line is going like this, coming here. So t vector in here if you draw, goes in.

And t vector in here comes out. The t vector in here is tangent to the dislocation line there. This is my t vector and t vector is not a constant. For a straight line it was. Now it is a curved line, it is not because at every point it has to be tangent. At this point it is perpendicular to that one. In here it is some other angle. So this is changing.

"Professor-student conversation starts."

Professor: And like this point which I have named as F here and this was named as H here, if I take this t vector which way shall I draw the Burgers circuit at this, around this point?

Student: Clockwise.

Professor: Clockwise, good. So what I do is I draw a clockwise circuit. I will not put anything counting. You can count the steps. This is exactly the same way we did earlier. I end up here, I start there. My end point and this is the Burgers vector. Burgers vector is this from Q to P. All right. In other words, let me show this Burgers vector here is this. That is my Burgers vector, all right. At the F if I come back, okay, I come back to F, now I draw it…..?

Student: Anticlockwise.

Professor: Anticlockwise. So let us, we start here somewhere else. I start at P prime, I end up at Q prime. You can count your steps. So Burgers vector is this. This is the Burgers vector. This Burgers vector and this Burgers vector, check that direction and magnitude. It is same. So Burgers vector of a dislocation line is invariant. Similarly if you find out the Burgers vector at this point, it will be the same. Why is it so? Why the Burbling vector is not, is invariant?

Whether I take this shape of the slip part or I take some other shape of the slip part, push which I have given is the same constant. Push is the constant, direction and magnitude that is the constant. That is why whatever may be the shape of the boundary between the slipped part and unslipped part, this slip segment or the vector, slip vector by which one part has slipped with respect to the other of, in the crystal is the same. Everywhere it is the same, it has not changed.

t vector of course is changing because that is a tangent to a dislocation line and dislocation line need not be a straight line. Therefore this tangent will keep changing. Is that clear? We shall start from here in the next class.

"Professor-student conversation ends."