Mechanical Behavior of Materials-1
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Lecture - 18
Dislocations: Characteristics

Welcome back students. So today we will continue our discussion on dislocations. So we are now well versed with some of the very fundamental characteristics of dislocation. We know that there are two types of dislocation, edge dislocation and screw dislocation. And now we will continue our understanding about dislocations.

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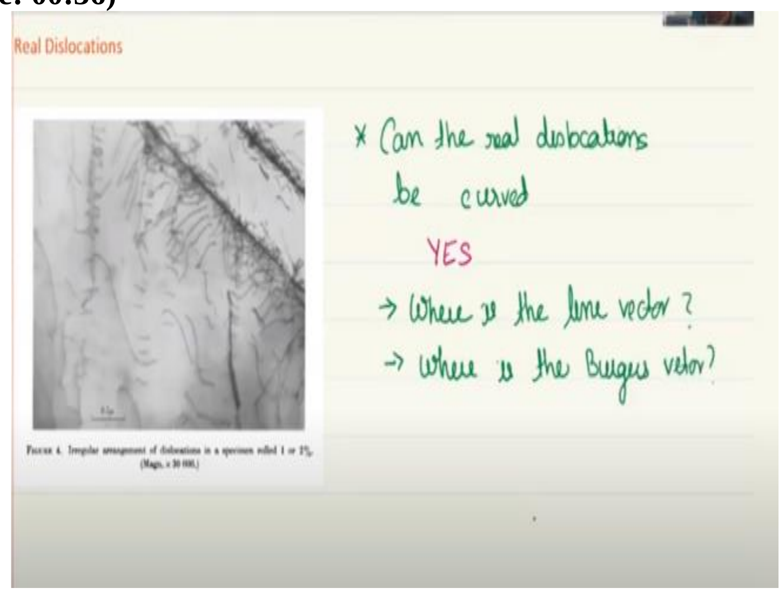

This is a TM micrograph from journal taken to showcase, which showcases how a dislocation looks like in a real material. So we are now moving on from the ideal visualization of dislocation, which was edge dislocation and a screw dislocation and the way we showed it. It was a straight line. But now what we see? We see that the dislocations are actually curved.

So the first question is can the real dislocations be curved? And the answer is obviously yes, because we see that these are, these are nothing but the curved dislocations. So these are dislocations and these are curved. And therefore, curve dislocations do exist. So yes. Now if that is true then the next question that we should have in our mind is then in a curved dislocation where is the line dislocation, line vector and where is the Burgers vector, okay.

So to understand this, let us draw again a little schematic of this kind of curve dislocation. So I will draw it like this.

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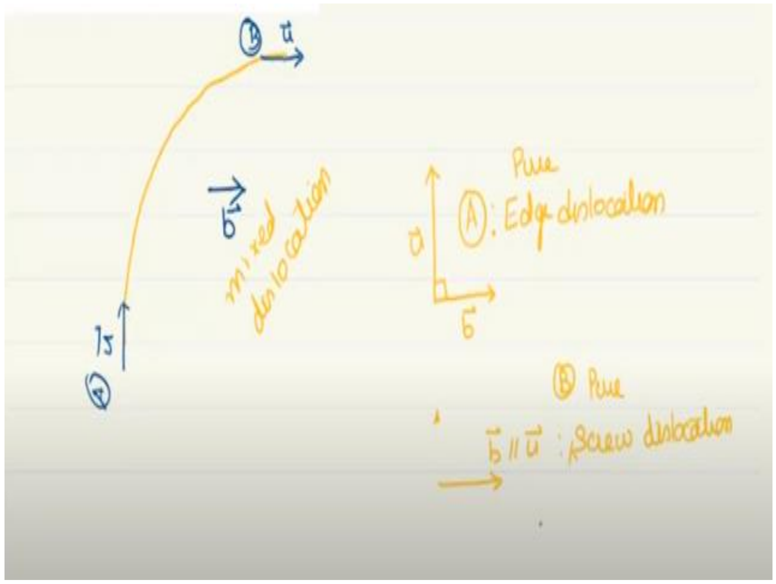

Now here, where would be the line vector? So line vector is as the definition goes should be the tangent to that. So at this point, this should be the line vector. At this point, this should be the line vector. So the line vector keeps changing with the dislocation. So let us call it point A. And let us call this point B. So at point A line vector is here and at point B the line vector is in this direction.

Now what about the Burgers vector? So if it is one unique dislocation or one individual dislocation, what will happen to the Burgers vector? And the answer is that the Burgers vector remains constant. It should not change with the location on the dislocation. Because Burgers vector if you remember is a slip vector. It defines which direction it will cause the slip.

Now just because dislocation is curved, which means that the extra half plane at one point and some place says it is the spiral kind of structure so that is how you get this curved dislocation. So now that should not change the direction of the slip vector. Otherwise, it will lose the meaning. Therefore, the Burgers vector must remain constant. And let us say this is the Burgers vector.

So the Burgers vector remains constant and this is how it will look like. Now let us look at point A and point B separately. So at point A we have, this is the line vector and this is the Burgers vector. So here it is perpendicular and we remember that the perpendicular relation between Burgers vector and line vector is in the case of edge dislocation. Now let us look at point B.

So here we see that line vector is in this direction, Burgers vector is in this direction. So here this is Burgers vector, which is parallel to line vector and we know this is screw dislocation. But only at point B and only at point A you have edge dislocation. So at point A this is a pure edge dislocation and at point B you have a pure screw dislocation. And in between this what we have is called a mixed dislocation.

So what is real dislocation is actually a combination of edge dislocation and screw dislocation. It is it has both partly edge characteristics and it has partly screw characteristics. Only at certain points where the Burgers vector is perpendicular to line vector there it will be pure edge dislocation and at a certain point where the Burgers vector is parallel to line vector it will be screw dislocation.

Otherwise, as you can see from this schematic it is very clear that a real dislocation would mostly be composed of what we can now call as mixed dislocation. So let us look at little bit more into the mixed dislocation.

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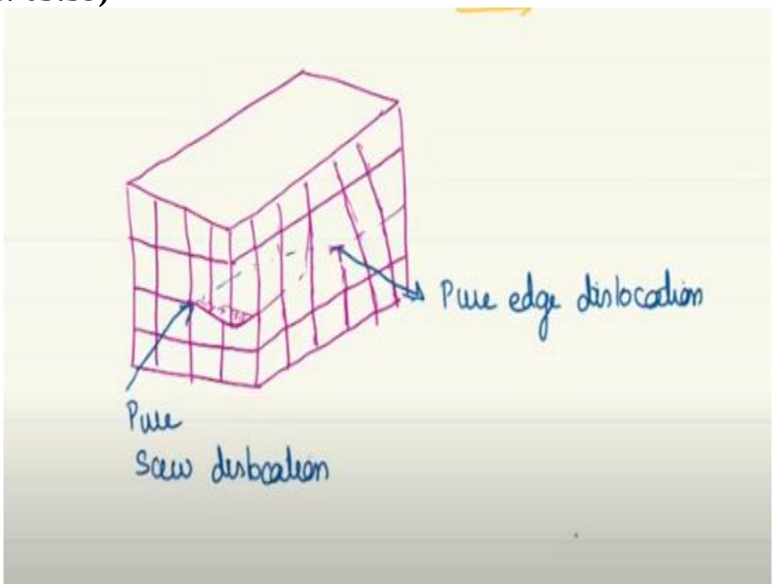

So if we are to draw it this is, so these are the lines along which atoms are aligned. So you can clearly see that there is extra half plane over here. So here this edge dislocation would look something like this. And on this side what we have is a spiral character which would look something like this. So this is the extra part of this spiral character and now you can clearly see that there is a edge dislocation type of character here.

So this is let us say this is the line vector, this is going in. So somewhere over here the line vector goes like this. And if you go look from this direction you can see it is pure screw dislocation. And when you look from this side you would see it is pure edge dislocation. So on only at this particular point it is a pure screw dislocation and only at this particular point it is a pure edge dislocation.

And somewhere inside all and everywhere inside this, it is a continuous line and it is it has a mixed dislocation character. And now this obviously raises a question or curiosity how does the atomic structure look like inside? Or how does the mix of edge and screw look like inside this material.

And it is not very easy to draw the 3D structure but at least we can try to draw the 2D plan view of this kind of structure. So this is how it will look like.

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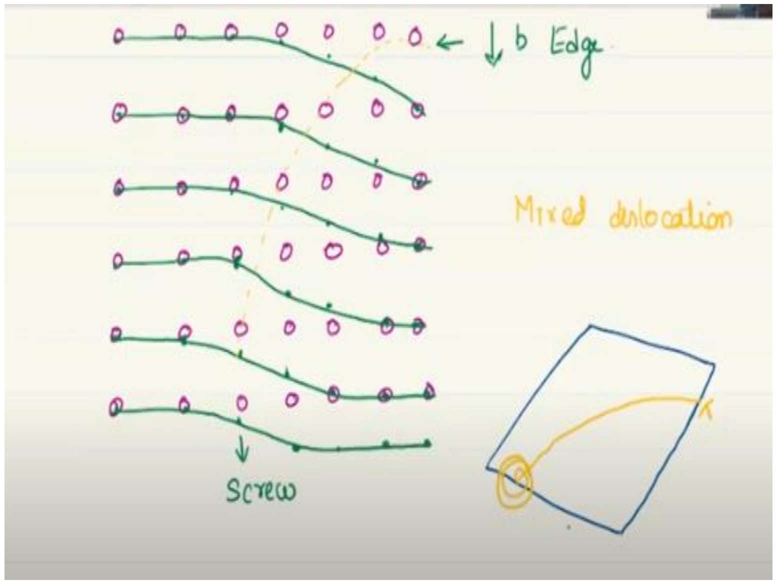

So this I am drawing the layers on the bottom where everything is perfect. Now let me draw the atoms which is in the green color, which is on the top layer and in this particular layer you would see the defect. So this particular row is alright. In this particular row let us say that it gets shifted just a little bit. In this row again it has to be shifted. So all the way up to this point it may look like it is okay.

So what we see here you can now clearly visualize that on this side on the bottom side of the image. Now we can clearly see a screw character. On the other hand, if you look on that right side over here, what you would see is a edge character. So here you can see it is a missing plane of atom over here, an extra half plane is on the bottom side.

So we can say if this is the line vector somewhere like this the Burger vector would look like and this is a pure edge dislocation over here. On the other hand, if you look if you are looking from this side, you would see that there is a spiral structure and therefore, there is the line vector coming out like this and this is a pure screw dislocation. So your core of this dislocation would somewhere go like this.

So like I said that the structure is not so simple to draw particularly in 3D, but in 2D view or plan view we can see how it is changing. So here it is a pure edge dislocation type and slowly the atom displacements keep changing until this point where it looks completely like a screw dislocation.

And the above layers would keep shifted, keep getting shifted just a little bit until we again get a pure or perfect crystal on the top side. So this shows a very nice way to visualize the mixed dislocation. You can also draw it like this. So on here we have extra half plane was going down. Let me draw it with a different color. So over here you have the extra half plane and over here you have the screw dislocation.

So this is the pure edge and this is the pure screw dislocation. Now when we have this kind of structure, then the question is how do we find the Burger circuit? That is also something we discussed last time. But in respect to a mixed dislocation, how do we find the Burger circuit and it is not very difficult.

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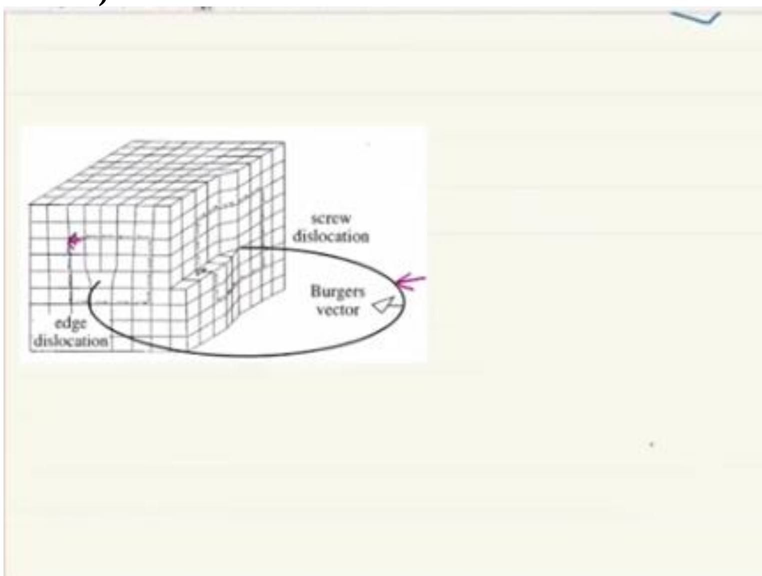

So for that I have used the picture from one of the books and you can see that over here you have the pure screw dislocation and over here you have the pure edge dislocation. Now if you use the convention that we used earlier and you draw the Burgers circuit just like that, you would be able to get a Burgers vector.

So in this case using this convention, they get this particular Burgers vector for the screw dislocation and when you use the same convention and using the same line direction, then you would see, or the same sense of direction not the same line direction, so you would see that here also you would get a Burgers vector like this. So the Burgers vector will come out to be consistent, it has to. That is the purpose of using the Burgers circuit and using the convention.

So that brings us to complete understanding of a screw, of a mixed dislocation. Now that we understand that overall the dislocations would be mixed in nature, some more characteristics are important to understand. So for example, let us go back and let us take a look at the dislocations over here, okay. Here it seems that the dislocation starts from here and here. This starts from here and here and so on.

So all of these dislocation look like they start somewhere from inside the crystal and end inside the crystal or terminate inside the crystal. But that is something that is not possible. So there are actually only three ways that a dislocation can terminate inside a crystal. Let us look at what are those three ways.

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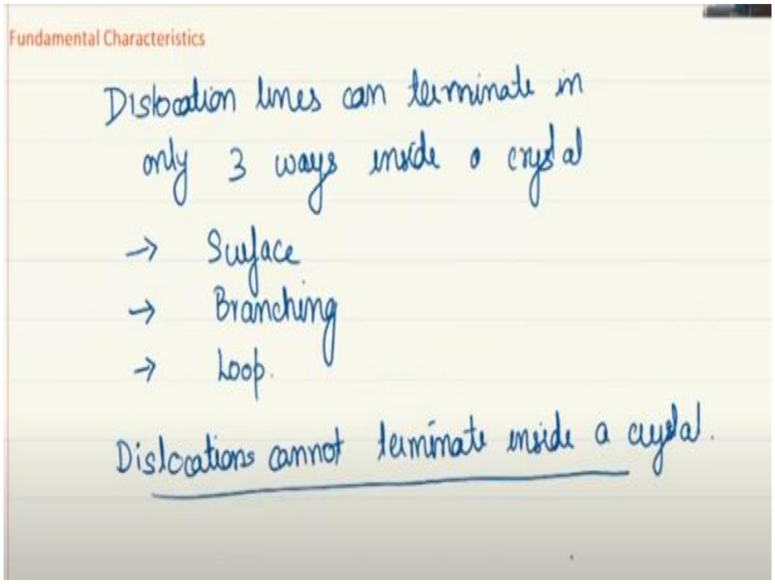

The three ways are one, the dislocation, end of a dislocation command can come onto the surface. And therefore it will create a step and with that step it will get terminated. So it can get terminated on a surface. That is one way for a dislocation to terminate. Another is by branching. So let us say one dislocation, it gets branched out into two other dislocations.

So this original dislocation gets terminated in some sense here and two other dislocations get arises from there. You will see this kind of example, particularly for face-centered cubic material where we have partial dislocations. So the other way is branching. And the third way is that it can form a loop. Meaning it comes back and ends on its own. So loop, forming a loop.

So this is, these are the three ways that a dislocation can terminate. And certainly it does not include that a dislocation can terminate inside a crystal. It is it clearly says that a dislocation cannot terminate inside a crystal. This becomes very clear when you understand these three ways of terminating of a dislocation.

But then you would be, you would have curiosity that we just saw this image where we saw that dislocation starts inside the crystal, ends inside the crystal. And the answer to this is that no this is not starting from the surface and not ending inside the surface. This in TM what does, what we use as a sample is actually a very thin foil of the order of 200 nanometer.

So what you are seeing is that one edge, one side of the dislocation is basically one surface. And the other side is maybe other surface or maybe after forming a loop it comes back. So it is a very thin surface like this or you can imagine page, a simple page like this. So you are looking at a very thin hair, which is inside it.

So the one edge of the hair is intersecting with one surface and the other is intersecting with other surface. Or it is also likely that it may start from the same surface, form a semicircle type some circular loop and come back to the same surface. So in either case, what is happening is that the dislocation is starting and terminating at the surface. That is what we are looking at over here.

So that should make it clear that dislocations cannot terminate inside a crystal. Another important fundamental characteristics that we realized when we looked at the dislocations is that the Burgers vector for a given dislocation remains constant irrespective of orientation of dislocation. So it is a corollary of this but I have written it as separately.

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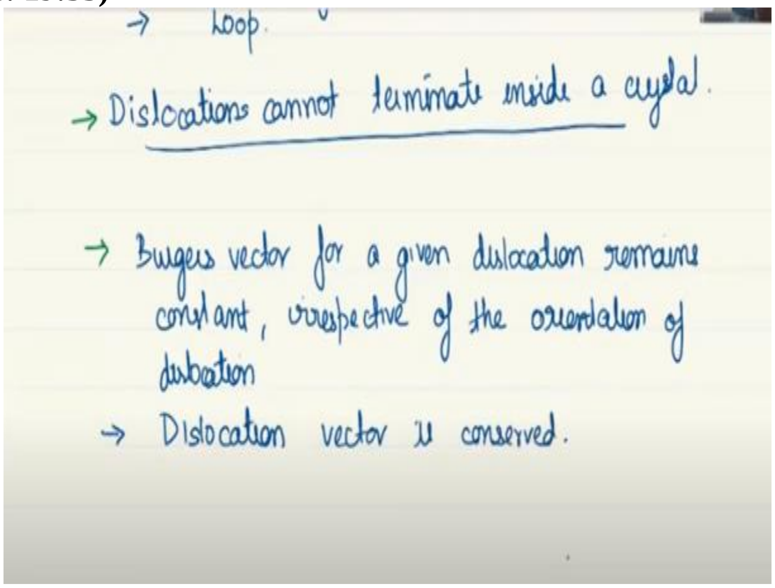

This we observed particularly when we were understanding mixed dislocations irrespective of the orientation. And last and the most important one is that dislocation vector is conserved. What do we mean by this?

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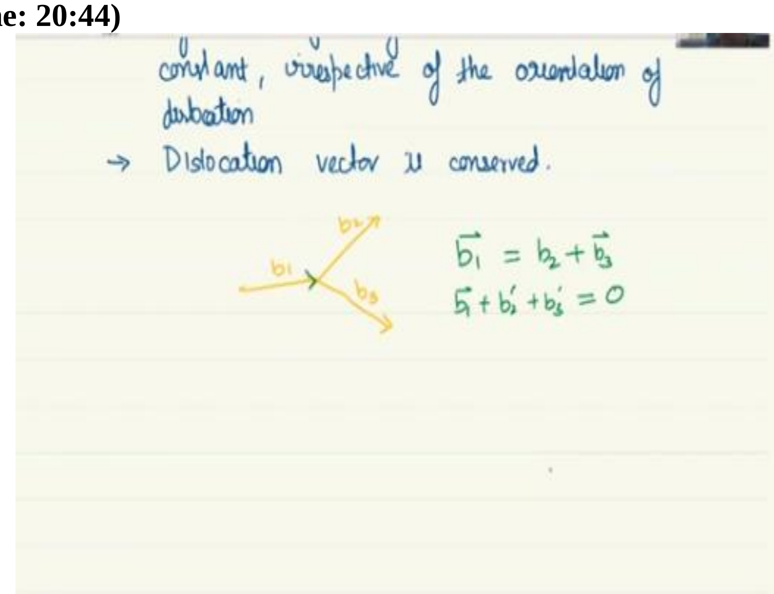

So let us say we have a dislocation going on like this. So this is Burger vector $\overrightarrow{b_1}$ and it branches into two dislocations with Burgers vector $\overrightarrow{b_2}$ and $\overrightarrow{b_3}$. Then what it is saying is that

$$\overrightarrow{b_1} = \overrightarrow{b_2} + \overrightarrow{b_3}$$

or if we say that the Burgers vector would be positive when it is going into this node, then we can say we can put it like this $\overrightarrow{b_1} + \overrightarrow{b_{2'}} + \overrightarrow{b_{3'}} = 0$

So this is what it means where $\overrightarrow{b_{2'}}$ is negative of $\overrightarrow{b_2}$, $\overrightarrow{b_{3'}}$ is negative of $\overrightarrow{b_3}$. And this tells you that Burgers vector will remain conserved, okay.

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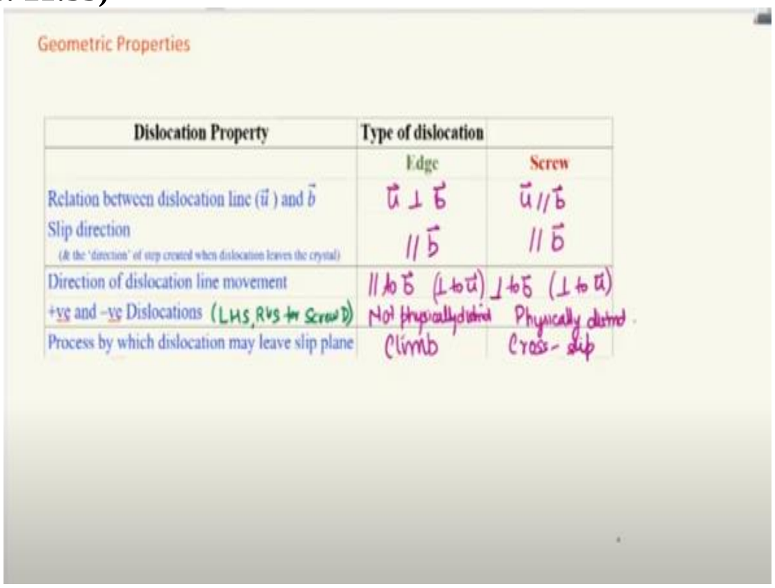

So now that we understand edge dislocation, screw dislocations and some fundamental characteristics of the dislocations, we are now in a position to understand some of this, some of its geometric properties. We have already understood it, we will now in a way summarize it. So what is the relation between dislocation line and the Burgers vector? We know that there are two types of dislocations, edge dislocation and screw dislocation.

So answer would be different for both of them. So the relation between line vector and Burger vector is perpendicular. So $\vec{u}$ is perpendicular to $\vec{b}$ for edge and $\vec{u}$ is parallel to $\vec{b}$ for screw. What about screw dislocation with respect to the Burgers vector? We know that Burgers vector is also called a slip vector.

And therefore, it identifies the slip direction, which means slip direction is same as Burgers vector or slip direction should be parallel to Burgers vector and this would be true for both edge dislocation as well as screw dislocation. So let me put a vector symbol over here now comes another very important point which you should keep in mind because it all it is a little bit you can say confusing at times.

What is the direction of dislocation line movement, okay. So it is not that the dislocation line will always move in the direction of the slip vector, okay. So the direction of the dislocation line movement will in case of edge dislocation it will be parallel to the Burgers vector which means it will be in the same direction as the slip vector.

But in the case of screw dislocation and we showed it in the previous lecture, in the case of the screw dislocation it moves perpendicular to the Burger vector. Or in other words you can say that in both the cases it moves perpendicular to the line vector. So it is parallel to Burger vector and in this case it is perpendicular to Burgers vector or in both cases we can say it moves perpendicular to line vector.

Positive and negative dislocations. So in the, or basically in the case of screw dislocation we are talking about LHS and RHS. So let me say, so for positive and negative distribution what do we know in about the positive and negative edge dislocation? We know that they are not physically distinct. So these are basically definition dependent, so not distinct, not physically distinct.

But LHS and RHS are physically distinct. And this is about their motion, okay. We have not talked about the motion and I will just take a leap here for your reference. It will serve as a good reference in the future. So process by which dislocation may leave slip plane. When it comes to edge dislocation, it can leave the, usual motion would always be in the slip plane.

In the slip plane because it is that plane which describes which is described with a Burger vector and the line vector, which are both perpendicular. So it is a unique plane. And in most cases, in most low temperature deformation processes, dislocations remain fixed in their own glide plane. But if you are working at high temperature, then they may leave the slip plane and that happens by client process.

On the other hand screw dislocations, Burger vector and line vector both are parallel and therefore it is not unique. In fact it can be more than one particular vector or more than one plane on which the screw dislocation the one same screw dislocation is capable of moving. And the mechanism by which it leaves the original slip plane is called cross-slip. Now you would see that what we have described are characteristics of edge and screw.

Now the mixed would depend on a combination of all these and we will see. This becomes particularly very interesting when we talk about the cross-slip. So we have said that cross-slip is not, effectively we are seeing cross-slip is not possible for edge dislocation, but it is possible for screw dislocation. So what about the mixed dislocations? We will come to that when we talk about cross-slips.

And that is why I wanted to give you a heads up on this. So that gives us a very good understanding about some fundamental characteristics of the dislocations and in this regard, let me also introduce you to something called as dislocation loops. We know that this is one of the ways that dislocation loop can terminate.
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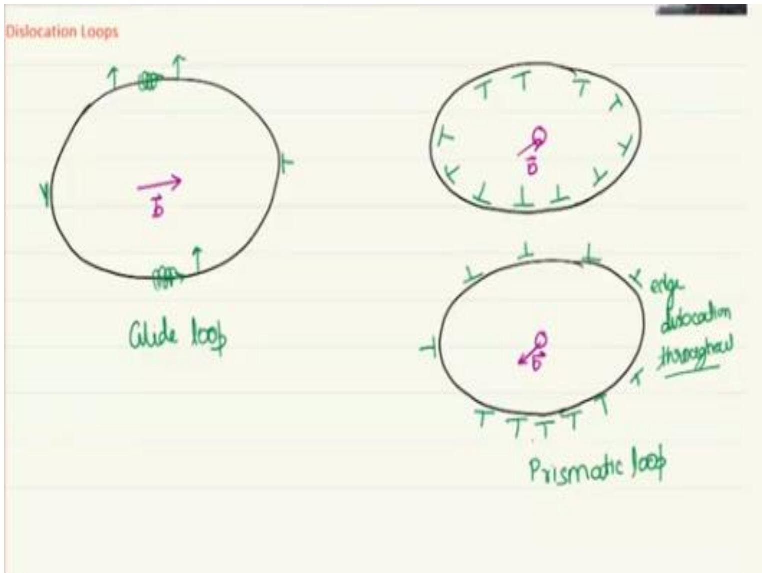

So let us say this is one dislocation loop. Now how would the Burgers vector look like for this particular loop? We have said that Burgers vector remains constant for a given dislocation line. So whatever with the Burgers vector it should remain same. Now if you look at it over here this is a some places it will have mixed dislocation, some places it will have screw dislocation, some places it will have pure edge dislocation.

And therefore this, because the edge dislocation is also somewhere over here and the mixed dislocation is also somewhere over here, therefore the Burgers vector would certainly lie in this particular plane somewhere. So let us say this is the Burgers vector. And if we say this is the Burgers vector, then we know that this here the line vector is parallel and therefore, there is a screw character.

So positive screw or negative screw like here. And at this particular place it will have a positive edge dislocation and here it will have a negative edge dislocation. So this is what is called as a glide loop. And why it is called a glide loop because its Burgers vector and line vector ensure that it remains fixed in particular plane. And therefore, it will glide in that particular plane.

However there is even another kind of dislocation loop. We all we want is that the Burgers vector should be constant. So how about having a Burgers vector which is perpendicular to the plane? So let us say this one is in this particular case it is coming out of the plane. What is the meaning of this kind of dislocation loop? If the Burgers vector is coming out of this and it is true for all the dislocation over here.

Now line vector is all in the plane which means Burgers vector is constantly perpendicular to the line vector, which means it is it must be an edge dislocation throughout. And what kind of, how can you get a edge dislocation throughout? One way is like this. So basically what you have here is the extra half plane is all on this side or meaning it is a cluster of vacancies.

It is a missing half plane or missing this oval type of plane and everything else is perfect. And therefore, if you are somewhere inside this, you will see that there is a plane all around you, but it is missing in that particular region. And therefore, it will appear as a extra half plane throughout.

Or it could be the other way around where it could be the negative of this. So there is extra small oval type of plane or island inserted between two planes.

So there is nothing continuing beyond this island. But this island exists between two layers and that would be opposite of this. So it will, if you want to draw this then it would look like this. So the extra half plane is over here now. And clearly you can see that line vector which is in the plane and the Burgers vector is perpendicular.

Therefore, it is edge dislocation and it forms a edge dislocation one by extra set of atoms forming island or set of vacancies clustering together to form a missing plane, missing island you can say. This one is missing island, this is extra island. And this kind of dislocation loop is called prismatic loop. And how would this like to move? Remember we said that motion would always be perpendicular.

So this could have been perpendicular in this particular case in the left one it can be perpendicular. So this one is moving in this direction, this one is moving in this direction and so on. The whole thing is shifting, that is how it will glide. But in this case it is edge dislocation. You cannot move in these directions, along these directions. It will have to move parallel to Burgers vector.

That is what we saw for the edge dislocation where we have a pure edge dislocation, which would mean that this whole thing has to shift and that is not so easy. It is a very complicated process. So usually this prismatic loop is what is called as sessile, not mobile. That is what it means, sessile type of loop. So these are some of the very basic fundamental some more characteristics about dislocation.

And now with this understanding we are in a position to look at some advanced information or knowledge theory about dislocations like stress field, strain field energy etc. Okay, so we will close this session. Thank you.