Introduction to Materials Science and Engineering
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Lecture – 58
Dislocation motion

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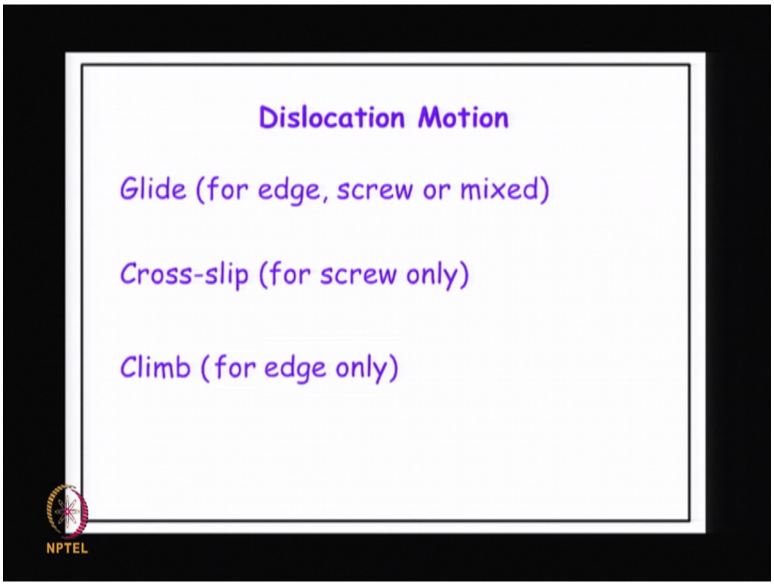

One interesting thing about dislocation is it is motion. Why dislocations are important in crystal because they can move under applied stresses. So, various kinds of dislocation motion are there, 3 of them are listed here the Glide motion which is for edge a screw or mixed so any type of dislocation can glide. Then there is a Cross slip motion which is only for a screw dislocation and a Climb motion which is only for edge dislocation.

So, let us look at them one by one. So, we will begin with dislocation motion in glide.

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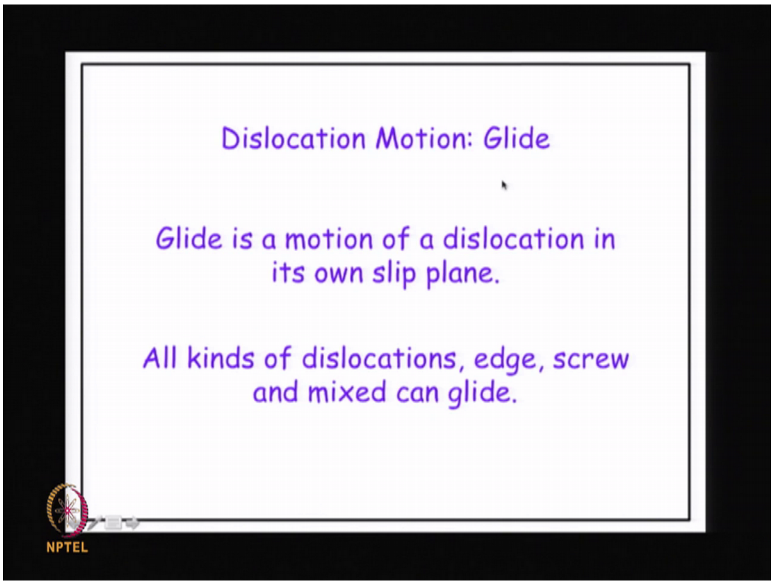

Glide is a motion of dislocation in it is own slip plane. So, every dislocation as you know as a slip plane defined by it is Burgers vector and the line vector. So, in case of edge and mixed dislocation there will be a unique slip plane because t and b are not parallel, in case of a screw dislocation since t and b are parallel any plane passing through the dislocation line can act as a slip plane. So, a screw dislocations have a non-unique slip plane.

So, whether unique or non-unique if the motion is confined to a given slip plane and that motion is called a glide motion and that is why it is possible for edge screw and mixed all dislocations can glide. Let us look at what is meant by the glide motion of an edge dislocation.

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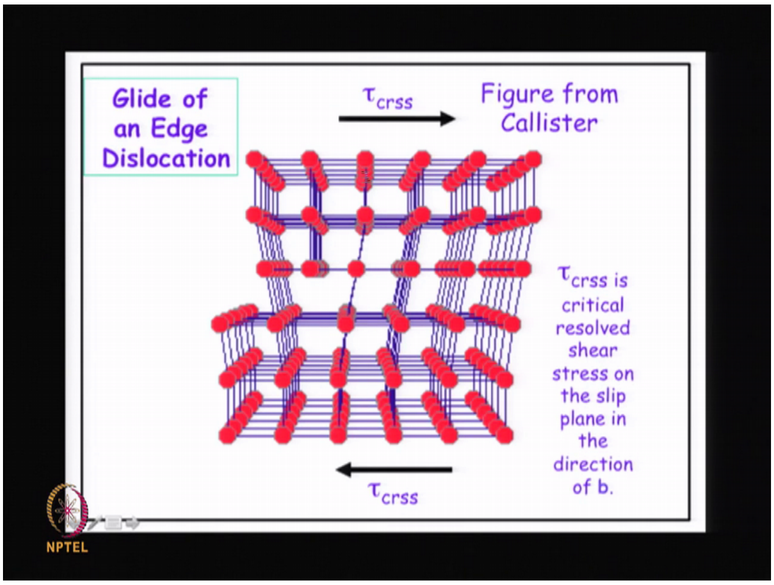

So, here is a picture of edge dislocation you can see an extra half plane. And so, the bottom edge of the extra half plane here going into the plane of the picture you have the dislocation line.

Now, this dislocation line if we apply a shear stress as shown here. So, with this symbol tau and this arrow we are showing that we are applying a shear stress in this direction on this crystal. Now the tendency of the shear stress will be to shear the upper half of the crystal with respect to the lower half and the direction of the shear of the upper half will be towards the right that is the that is what this arrow is indicating.

So, to achieve this shear of course, the entire block of the crystal can move or this dislocation which is present can move and we will see it is much easier for the dislocation to move than the glide of the entire half of the crystal. So, for this dislocation to move one step you can see that there is no bonds from here bonds have broken lower half of the plane is missing and you we have a continuous plane here, but there is some distortion in the bonds to accommodate this extra half plane.

Now, if somehow this set of bond breaks here where I am pointing the arrow now, the set of bonds break and it connects with this extra half plane, then you can see that this extra half plane now finds a partner below and becomes a continuous plane of course, a slightly distorted one, but it will become a continuous plane whereas, this plane the upper half of the currently continuous plane will now be hanging as an extra half plane.

So, a dislocation line which was located here will move from here one step to the right at this location, this is what is involved in the glide of an edge dislocation.

Let us try to see this pictorially the shear stress which I had applied was a small shear stress and a dislocation motion requires certain critical amount of shear stress. So, unless and until I increase the shear stress to that critical amount which is called the critical resolved shear stress we will have time to discuss it more later in the course, but currently we can just note that any stress any small stress in the crystal will not make the dislocation move, a minimum stress known as the critical resolved shear stress on the slip plane in the slip direction is required to make this motion possible.

So now as I press my computer keyboard, this plane this bond will break and will connect here such that the dislocation will move one step to the right so please watch that. So, you can see what has happened I will do that again once I will go backward, you can see the half plane currently the half plane if I count from here this is the first plane and this is the second plane from top.

So, currently on the top the second plane is the half plane. So, the dislocation line is the bottom end of the second plane, but as I move the bonds get connected here. So, we have a continuous plane now as a second plane and the half plane has shifted to the third plane. You can see that physically the half plane has not moved the original half plane is exactly where it was only a slight adjustment of the atom position makes the dislocation move. So, is the distorted configuration which is moving rather than the physical atoms jumping from one position to another. Physical atoms also are moving, but they only have to make slight adjustments to make the dislocation move, this is what makes the motion of dislocation much easier than moving the entire half of the crystal.

So, if I continue this motion so one more jump to the right then the dislocation line now comes on the 4th plane, one more jump on the fifth plane and a final jump brings it out of the crystal.

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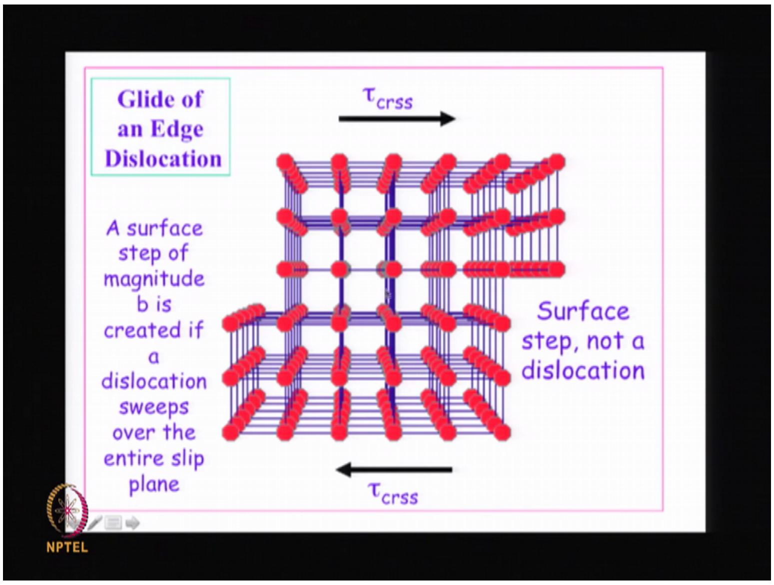

So, dislocation has now really disappeared from the crystal because this extra hanging plane we will not consider as a dislocation, but only as a surface step. You can see that because of the presence of the surface step here or in the beginning here, there is no internal distortion inside the crystal. So, these are not really dislocations in that sense half plane associated with this location, but only a surface is step.

So, to create this my unit surface step a dislocation has traveled through the entire slip plane and come out of the crystal. So, this is as I told is a surface step and not a dislocation and a surface step of magnitude if you look at the step magnitude the magnitude of the surface step is equal to the Burgers vector of the dislocation. So, a surface step of magnitude b is created if a dislocation sweeps over the entire slip plane.

So, this is the glide motion of the dislocation line you can notice that the Burgers vector was also horizontal and was pointing either to the right or to the left if I we take our convention and since it was a positive edge dislocation the Burgers vector was pointing to the right and the stress also is along the Burgers vector. So, the dislocation motion is also in the Burgers vector direction and the stress is also in the Burgers vector direction. The situation changing if we consider the motion of a screw dislocation.

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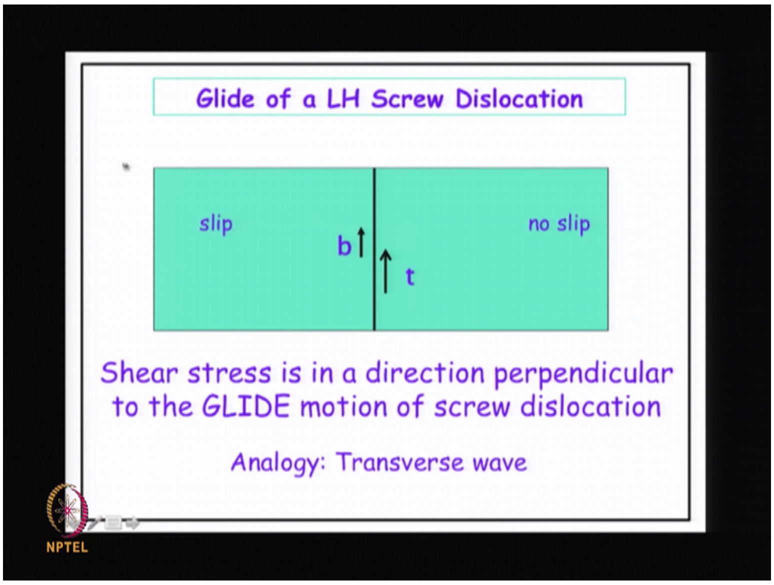

So now I have tried to show you a screw dislocation this is the slip plane and this is the boundary which divides the slip and the no slip parts of the crystal, and we have I have I am showing that the Burgers vector and the t vector are parallel which in our convention will give us a left handed a screw dislocation.

Now, if I want to make this dislocation move I will have to apply a shear stress the dislocation will move to the right, but the shear stress will be pointing up in the direction of the Burgers vector. So, I am trying to show

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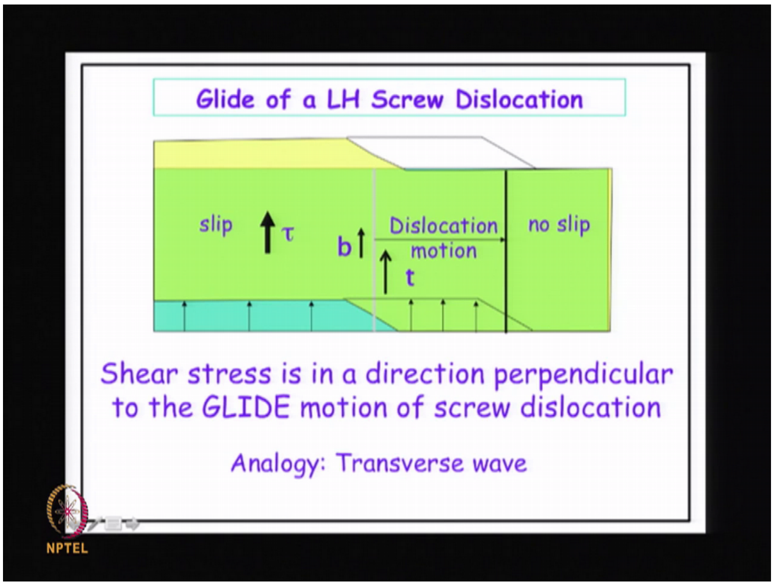

the slip associated with the dislocation line since this is the slip side, what I am showing by this drawing now that the upper half of the crystal, upper half means the half above the slip plane. So, the crystal above the slip plane had slipped with respect to the crystal below the slip plane in the direction of the Burgers vector by this much amount.

Now, if I wish to move this dislocation line to the right, then what do I have to do? Let us see if the dislocation line moves up to this location which means the slip side will now extend up to this line. So, this part which was currently unsliped due to the dislocation motion that will also become the part of the slip crystal, which means this region which has not yet slip will slip in the direction of the Burgers vector to create this dislocation motion because the boundary has now shifted. So, these atoms also will move in the direction of the Burgers vector.

Now, to create this motion of course, we have to apply a stress which is in the direction of the atomic motions. The stress which will be required to create this motion will be in the direction of the Burgers vector. So, we see the interesting situation that we apply a shear stress in this direction which is the direction of the motion of atoms required; however, the dislocation line moves in a direction perpendicular to the applied stress. In the case of edge dislocation, we saw that these 2 directions were the same the shear stress direction and the motion of the dislocation were in the same direction, but in a screw dislocation the shear stress is applied in one direction and the motion is in a direction perpendicular to the applied shear stress.

An analogy sometimes is given of a transverse wave in which you know that the wave propagation is in one direction which is perpendicular to the direction of actual motion of atoms. So, similarly here the actual motion of atom is in this direction, but the motion of the dislocation is in a direction perpendicular to the actual motion of atoms. So, to summarize the glide motion and the shear stress relationship for both edge and screw dislocation in both cases the motion is perpendicular to the dislocation line. The motion of a dislocation line parallel to itself makes no sense the motion whenever a dislocation line shifts it will shift perpendicular to itself.

So, both edge and screw dislocation the glide motion is perpendicular to the dislocation line. The shear stress were calling the motion in case of edge is in the direction of the motion, but in case of a screw it is perpendicular to the motion, but in both cases the shear stress is in the direction of the Burgers vector which is the actual direction in which the atoms move. So, in that completes our discussion of glide motion we now take up the cross slip the cross slip of a screw dislocation.

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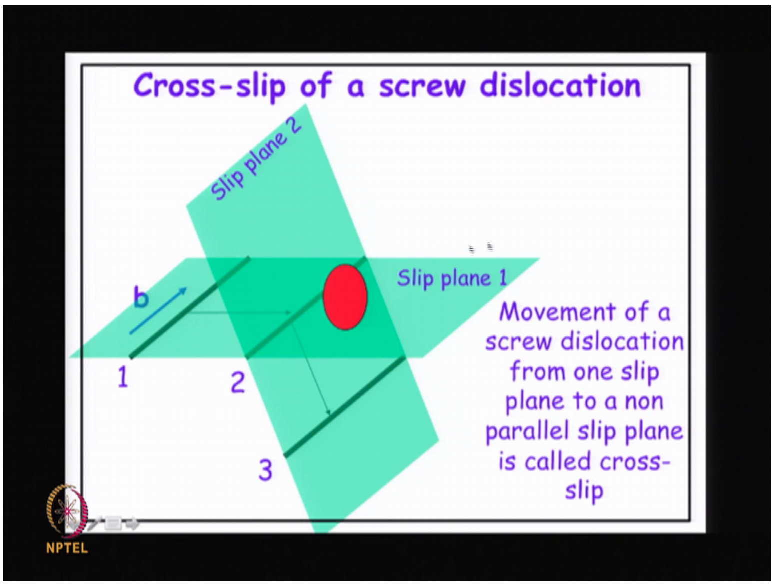

So, here I am a schematically showing a slip plane I have labeled it as a slip plane 1 on which I have shown a dislocation line 1 at location 1, and I have shown a Burgers vector which is parallel to the dislocation line making it a screw dislocation. Now I am thinking of a motion of this dislocation in it is slip plane from location 1 to location 2.

That will require a shear stress as we have seen I am not showing that, but assuming that we have applied the shear stress in the correct direction of the correct magnitude which is the critical resolved shear stress then this dislocation can move from location 1 to location 2, but beyond location 2 let us assume that there is some obstacle some kind of obstacle we will study about these obstacles later on in the course.

So, this may be precipitate particle or maybe other dislocation and so on. So, we are currently I have shown it as a precipitate particle. So, suppose there is a precipitate particle an obstacle in the motion of the dislocation such that it cannot continue it is motion on the slip plane 1; however, since it is a screw dislocation any plane passing through the dislocation line is a possible slip plane.

So, we can think of another slip plane slip plane 2, which is also passing through the same dislocation line and if the applied shear stress is sufficient to for it to move on the slip plane then this dislocation can happily change it is from slip plane 1 to slip plane 2 and it will start moving in another direction on the slip plane 2 to avoid this obstacle. So, it is possible since screw dislocation has many slip planes passing through; it all planes which pass through the dislocation line or a possible slip plane and if the shear stresses are sufficient for it to go from 1 slip plane to another it can do.

So, such a motion of shifting from 1 plane to another plane movement of a screw dislocation from 1 slip plane to a non-parallel slip plane is called cross slip you can notice that this kind of flexibility is not there for an edge dislocation because for an edge dislocation the slip plane is defined by b and t so only one set of parallel planes are the slip plane.

So, it cannot change to another inclined plane because it does not exist, but the edge dislocation also can avoid obstacles in it is motion by another kind of motion and that is called the climb motion.

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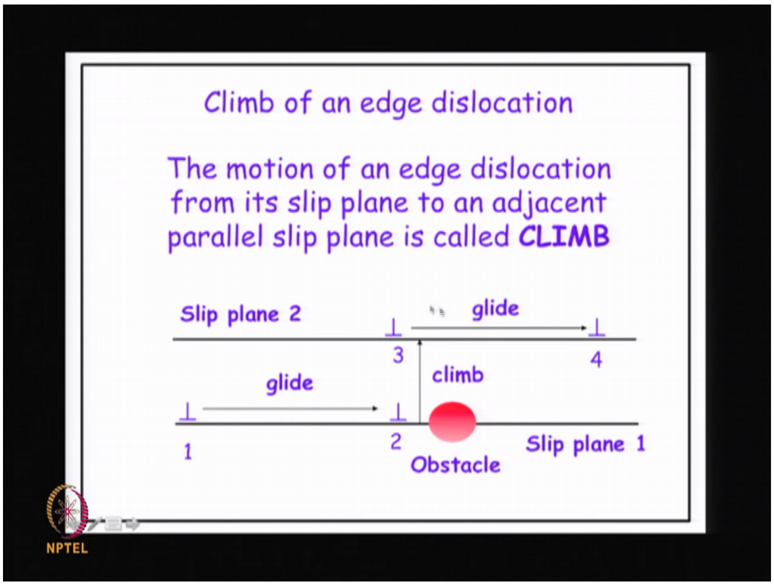

So, what it can do is to jump from it is slip plane to a parallel adjacent slip plane. So, I am showing it schematically here. So, this is the slip plane 1 on which there is an edge dislocation at location 1 this edge dislocation let us say moves to this location 2 this motion will be called the glide motion on plane slip plane 1, but after that just like we had obstacle for the screw dislocation let us assume that there is an obstacle to this dislocation for it is movement on slip plane 1.

So, it cannot now overcome this obstacle in the plane 1, but what it can do is to jump to a parallel slip plane on which the obstacle is not there. So, it can jump from location 1 to location 3 to a parallel slip plane and this motion will be called a CLIMB motion, and once it is on slip plane 2 since the obstacle does not extend to slip plane 2 it can then happily glide on slip plane 2 to the location 4.

So, a jump from one slip plane to a parallel slip plane of an edge dislocation is called the climb motion. Let us look at this is only showing it is schematically and graphically we are not explaining how it dislocation line from 1 plane can jump to another plane. This we can explain

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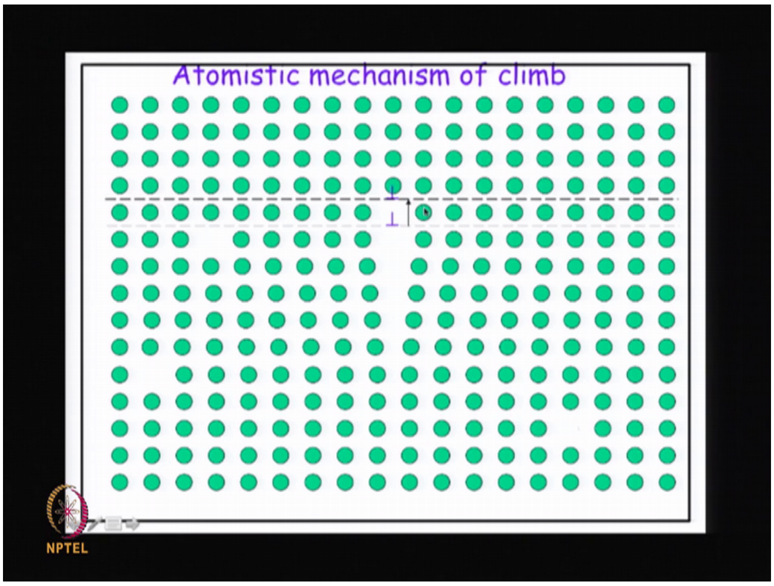

Here with the help of this picture which is trying to show the atomistic mechanism of the climb. Notice this is a large crystal face which you are seeing there is an extra half plane here. So, there is a dislocation line there deliberately I have also left certain sites vacant which are vacancies.

Now, vacancies are always in equilibrium with the crystal. So, a crystal having dislocation will also have certain number of vacancies and these vacancies are important as the vacancies are the ones which assist the dislocation to climb. So, I have put a vacancy very close to the dislocation line. So, dislocation line is here this is the extra half plane the bottom edge of the half plane is the dislocation line and a vacancy is sitting rather close to the dislocation line.

Now, let us see with this symbol upside down t I am showing that the dislocation line currently is here and if you remember the Burgers vector of this dislocation line will point to the right. So, this horizontal slip plane shown in the trace here in this dashed line is the slip plane for this dislocation this is the current slip plane of this dislocation, but now suppose this atom at the bottom edge the atom at the bottom edge jumps to the nearby vacancy, atomic jumps like this are possible vacancies and atoms can interchange their position. So, if the atom here jumps to the nearby vacancy then what happens then the extra half plane now is ending one plane above.

So, the edge dislocation which was currently here has now jumped to this location one step above. So now, after this jump the slip in the dislocation line is lying on an adjacent parallel slip plane. So, this motion from this location to this initial location to this final location this motion this jump motion is what is called the dislocation climb, in particular we will call the dislocation is climbing up. You can think of a reverse situation in which an atom from a nearby side joins the dislocation line, in which case the motion will be reversed and the dislocation line which is here the extra half plane will now extend to up to a lower level and the dislocation line will come down one level and that will be a climb down.

So, both climb up motion and climb down motion is possible for the dislocation and in both vacancies are involved because you saw that there was a nearby vacancy which got filled because of the motion of atom here. So, for a climb up motion atom should move away from the dislocation line into the vacancy. So, vacancies assist them, but in this process also vacancies are reduced in number because vacancies are filled by the atom coming from the dislocation line.

So, for a climb up motion the dislocation for climb up motion the vacancy concentration in the crystal will go down. The reverse will be true for climb down because if it is climbing down you require an atom to come and join the edge dislocation line and wherever they come from they will come from a nearby site and wherever they come from they will create a new vacancy there. So, if a dislocation climbs down the vacancy concentration will go up.

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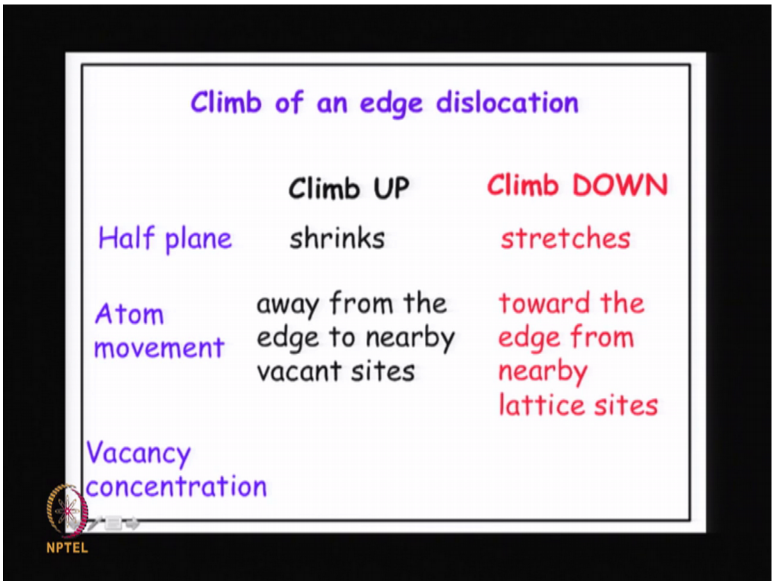

So, we summarize this in this slide that, if we call climb up it means the up and down is important to see when I was showing you in the last slide that up and down is not necessarily related to our coordinate system or our up or down up and down is with respect to the dislocation line and actually climb up will simply mean that the half plane is shrinking. So, if a half plane is shrinking the dislocation line is climbing up in reverse if the half plane is stretching extending by joining of atoms it is climbing down.

So, for shrinking atoms have to move away from the dislocation line and where they will move to they will move to the vacancies to the vacant site. So, atom movement is from the edge dislocation to the nearby vacant sites, in climbing down since we have a stretching plane we require atoms to add to the dislocation line. So, atoms will move towards the edge from nearby lattice sites and those lattice sites will now be left vacant.

So, the vacancy concentration for climb up will go down and vacancy concentration for climb down will go up. So, we end this discussion on dislocation motion by once more summarizing that we discussed 3 kinds of dislocation motion, the glide motion which is motion of a dislocation in it is own slip plane, cross slip which is motion of a screw dislocation from one slip plane to a non-parallel slip plane and climb which is for an edge dislocation is jump from one slip plane to another parallel slip plane.