Principles of Physical Metallurgy

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Lecture No. # 12

Crystals Defects in Metals (Contd.)

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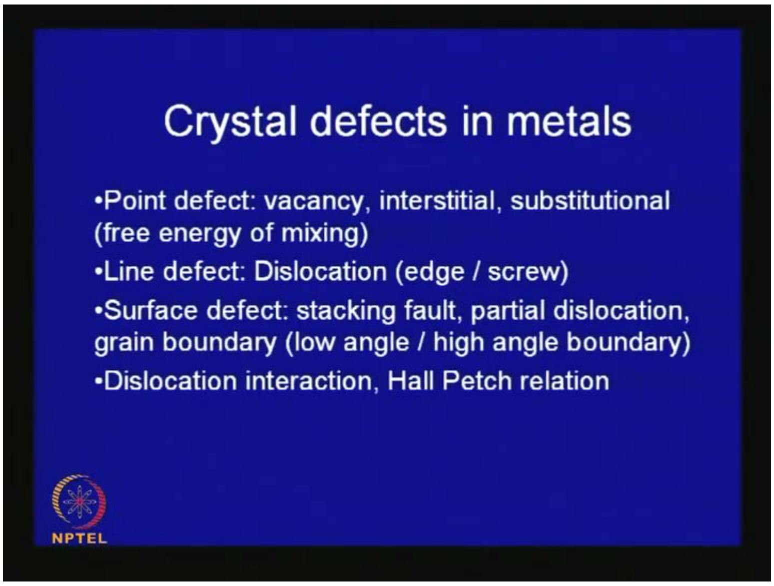

Good morning. Today also we will talk about crystal defects in metals. Last couple of classes, we introduce the concept of point defect like vacancy, interstitial atom, substitutional atom. We also looked at the effect of temperature on concentration of vacancy, we also looked at length about line defect that is dislocation, which is a boundary between deform and undeformed region or slip and unslip region. We talked about two basic types of dislocation that is edge, and screw. We also looked at the nature of stress field surrounding at dislocation. And today we will talk about a part of this dislocation interaction. We will also look at defect surface defect called stacking fault.

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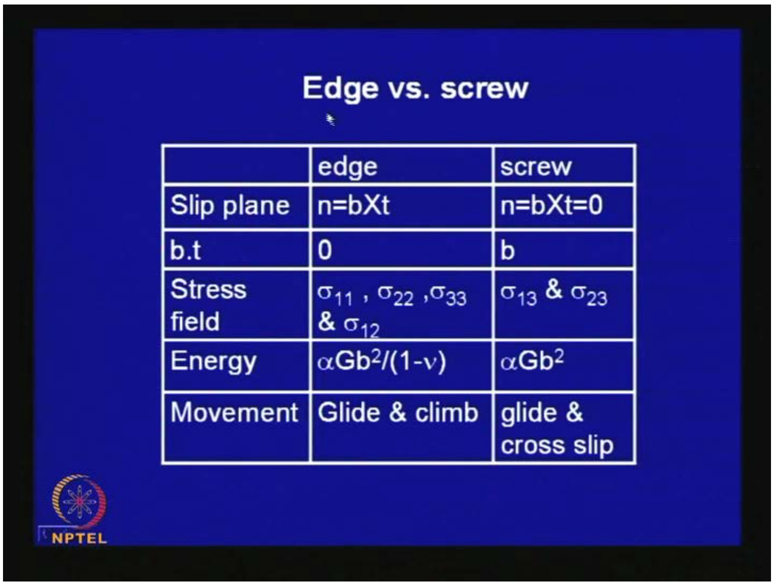

And to sum up you know we looked at two types of dislocation that is edge and screw, if you look at their characteristic, which is listed here. These are certain features of edge dislocation this is the certain features of screw dislocation. In fact, when you look at a dislocation is basically you have to define two things.

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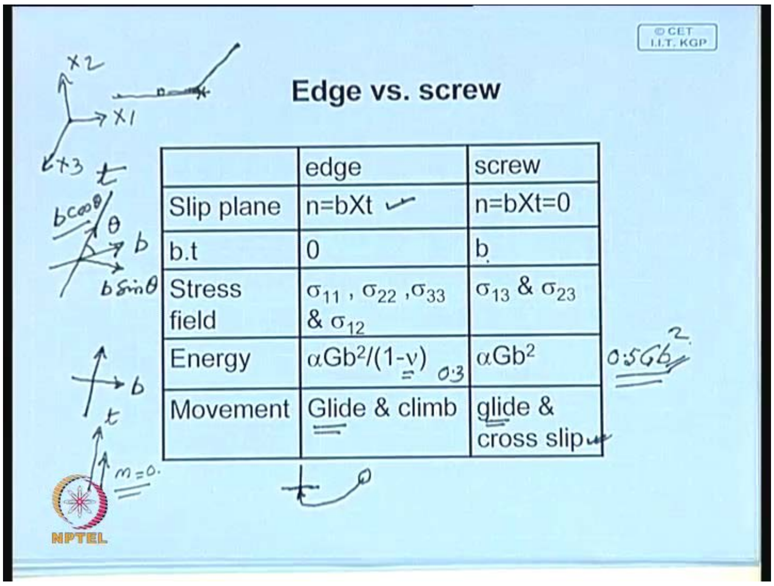

One is the dislocation direction and another you also need to define the Burger vector this is b. Say suppose, this is the unit vector presenting the dislocation direction t and this is the Burger vector and angle subtended is theta. Then clearly this is mixed dislocation and it has an edge component, which is like this b sin theta and this is the screw component, which is b cos theta Burger vector. Now, clearly if it is an edge dislocation say suppose if it is an edge dislocation this is the dislocation direction, this is the Burger vector it can slip only on the plane, which contains both t and b and therefore, the slip plane is given by this b cross t. Now, same thing if you try and do for screw dislocation. Screw dislocation this is the dislocation direction, this is the Burger vector.

So, if you take a similar thing this n comes out to be that the plane it comes out to be zero, b cross t is actually the vector presentation of the slip plane. In this case the n comes out be zero which means this is more mobile by glide it can pass through say suppose if there is a dislocation say suppose here this is one plane a screw dislocation moving it meets an obstacle here. It cannot go beyond this and at that time say suppose, if there is another slip plane like this. There is a possibility it can move on this. So this movement is known as cross slip. So, which is listed here so if you look at this then the dot product between the b and t say in this case the dot product is b itself here it is zero and you look at the stress field.

Stress field is a basically if you assume the dislocation to be a line along the this x direction this is direction x 1, this is direction x 2 and you dislocation is line is along x 3 and in that case it was shown if it is edge dislocation it will have these component of stresses. If it is screw it will have these so look at the two I mean here this two are 0 whereas, here each of this for screw dislocation each of this component is 0. So together if you have the mixed dislocation you can say that all the six stresses will be six components of stresses will be present. We also estimate it the elastic stored energy in the dislocation and which comes out is of this order and this nu is actually Poisson ratio and we know for most metals this is around 0.3.

So, we can say on a rough say edge may be edge dislocation has a little more stored energy elastic stored energy then screw. But for all rough calculation to understand dislocation interactions will always assume that this is energy of dislocation is around say 0.5 G shear modulus b square. For many cases metal the G is constant so b square is directly gives a measure of the elastic stored energy of dislocation, dislocations having high or large Burger vector will be unstable. this is the reason why some of the you can try some of the ceramic crystals or sodium chloride crystal, if you look at the structure there the Burger vector this much larger than the Burger vector that you get in metallic materials, metallic crystals.

Now, about dislocation movement is said that primary movement is glide to slip both edge and screw can glide but screw dislocation glide not only on the present slip system, it can cross slip and to another slip system also, which edge dislocation cannot do but edge dislocation has another type of movement, which is through interaction. They can cease edge dislocation on extra plane of atom and if the vacancy lattice diffuses here, then the dislocation can climb up. Or else if the dislocation climbs now it will generate vacancy. So that means this is type of motion which is known as non conservative motion.

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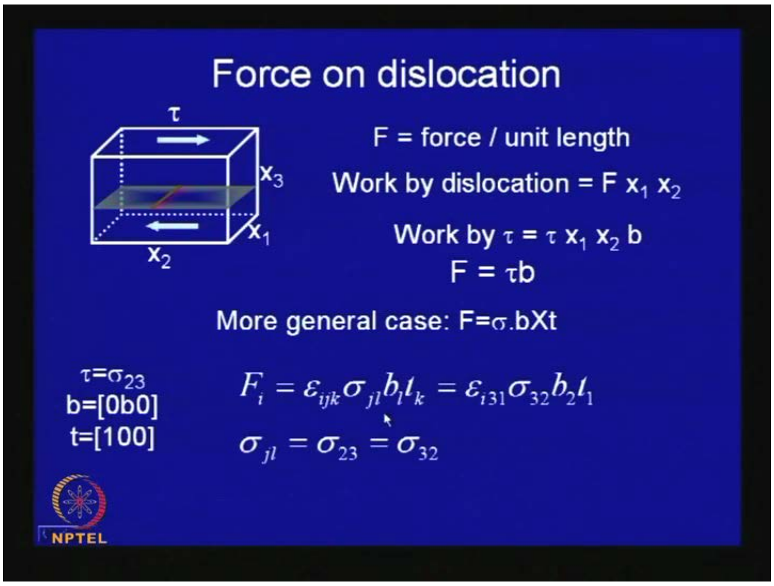

With this background, we also calculate it the force that acts on a dislocation and this is the if you try and recollect this is the crystal, this is the slip plane, where you have a dislocation and this dislocation line is a line along that direction this is x 1 along the direction x 1 and you have apply a shear stress tau and in this case simply we could calculate the force on the dislocation, which out comes to be shear stress on that particular slip plane times the Burger vector. This you can say this is for example, we can always say this is the resolve shear stress times Burger vector is the force on the dislocation.

So this is the force, which is responsible for the glide motion of the dislocation. But in a more general case often it is a not I mean the state of stress of elastic stress field can be much more complex. In that case in a more general case, how do we find out, which is shown over here, in a more general case if you have all components of the stress field to be present. So that means there are all six component of the stress field, the stress matrix is actually symmetric. We know there are six components of stresses and which is represented as the 3 by 3 matrix that is sigma. So, this is equal to sigma dot b it is the it is the vector although it is the dot product but it is the dot product with state of stress, which is a second rank tensor.

Therefore, this is also effect and if you take a cross product with the dislocation direction. So, this is the force acting on the dislocation. Now in this particular case what is tau? Tau is the shear stress acting on the plane, which is intersecting the x 3 axis. So, that means we can it can acting along the direction x 2 this distance is x 2. Therefore, tau is represented as sigma 2 3 whereas, here the dislocation is a line along this direction along x 1, the dislocation is a line along x 1. So that means this vector representing the dislocation direction we can say it is 1 0 0 so that means t 1 is non zero rest are zero whereas, the Burger vector is pointing if you assume this is the edge dislocation and Burger vector points along the x 2 direction.

Therefore, only x 2 component of the Burger vector is non zero rest are zero. So, let us see I mean how can we do i mean find out this force on the dislocation has taking this has a more general case. Now, here we will introduce it may be better if I introduce a concept called this is the repeated subscript or Einstein or Cartesian tensor using the Einstein convention of a summation, which is shown over here.

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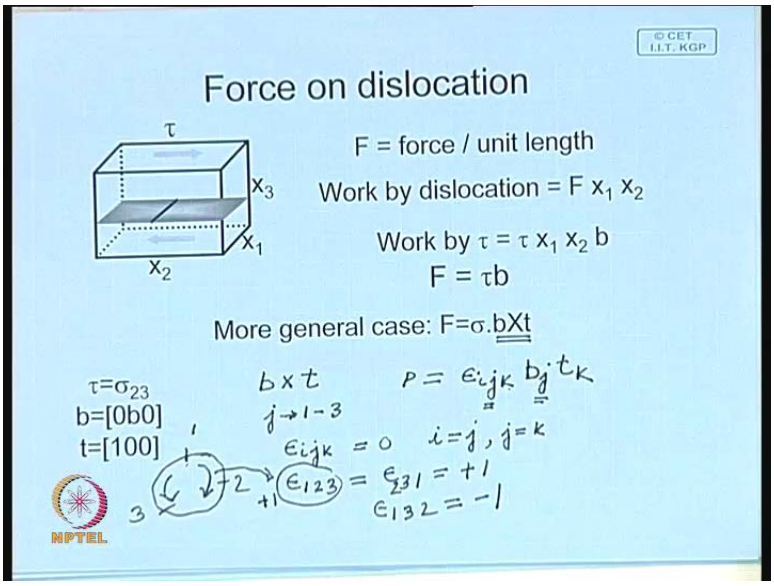

To more explicit, what we can do? We have find out a cross product is a basically say suppose if we do a cross product of two vectors b cross t. Now this vector I mean this can be represented as the cross product p can be represented as, we introduce another tensor epsilon i j k and we multiply this by b j and t suffix is k. Now here what it means if there is a repeated suffix it means summation over j and the j hence change is from 1 to 3 in a Cartesian system. Similarly, there is a summation over k as well. So k also changes from 1 to 3 and this tensor epsilon i j k.

So, this is a tensor of third rank and i j k can have values 1 2 and 3 and this is equal to zero. If any two of this suffix they are equal. Any two if they are equal then this is zero and if this is in this sequence 1 2 3 or epsilon 2 3 1. In this sequence then it is plus 1 then it is in the reverse sequence say suppose you imagine so this is 1 2 and this is 3. If it is 1 2 3 3 1 2 3 2 3 1 3 1 2, if it goes in this sequence, then it is plus 1. So that means if it goes in this sequence, then this tensor this it is magnitude is plus 1. If it goes in the reverse direction that means 1 3 2 epsilon 1 3 2, then this is equal to minus 1. Now with this if we apply that here and then we in that case this product sigma dot b cross t.

This will be represented as F i this is i th component of force. It can have three components along three directions x 1 axis, x 2 axis and x 3. So i represents that component and this is equal to epsilon i j k, this is a tensor of a third rank. Then sigma j l so sigma j so there is summation over j here and then sigma j l dot b. So, here you have b b suffix l, so that means this sigma j l b l where the suffix l is repeated, l can have value from 1 2 3. So, that means this represents this dot product sigma dot b and then you have t k. Now, here look at you know this convention how simply the calculation can be done.

Now, in this case only the b 2 component is non zero; b 2, which is equal to b. So, we write here, so l can be have value only two. Similarly, the suffix for t can be only one because the t 2 and t 3 both are zero. So, most of this there suffix this is 1, this is 2. Therefore, if this is 2 this component l is 2 we write two here. In that case we know if this is the dislocation if it is then let us seeing what can be the value of j. Now, j here the sigma you see only 2 3 is existing.

Now if 2 3 is there sigma 2 3 will also there. So, what we can do because sigma 2 3 is equal to sigma 2 3 so that means strength tensor is symmetric. So, this expression this is 3 2. So, then only unknown here suffix is i, now what can be the value of i, only number which is left is 2. So, 2 3 1 is equal to plus 1. Therefore, here you can see straight away this will be sigma 3 2 b. So, sigma 3 2 is tau so you get exactly this expression.

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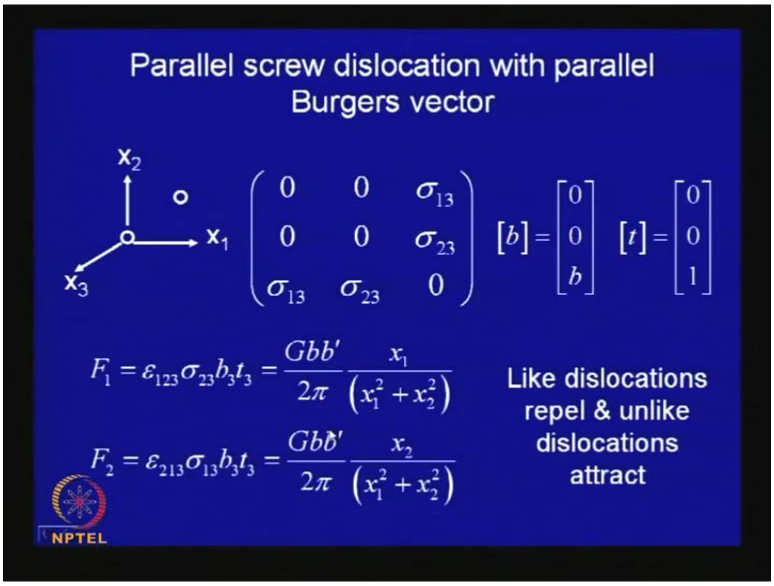

Now, why we did it at length because we have to look at interactions between two dislocations, if you want to find out each how will a dislocation will interact in presence of another dislocation. Now in this case what we have to find out look at the stress field of one dislocation and how it is going to react with this stress field of the other. So, which is shown over here say suppose we consider two parallel screw dislocation with a parallel burger vector. So, here this dislocation lies along the axis x 3 here and we say that on this another dislocation is here, which is also lined along x 3.

Now, this interaction nature of this interaction will obviously depend be this dislocations are arranged and therefore, this be taken very simple example here and we know the stress field of this dislocation, we know that this is the stress field these are these are the zero is stress component zero, only non zero stress component are this and since stress strength is symmetric this is equal to this, this is equal to that and here this burger vector is represented is also lying along the direction x 3. Now let us say this burger vector of this is 0 0 b. So, this is along x 3 direction and this dislocation direction is also parallel to x 3. So, this is also 0 0 1.

Therefore, you substitute back into this expression then you get this is b 3 t 3 only these are that non zero. So, obviously they are not many choices. You have two components F 1 and F 2 and we have taken this burger vector say suppose one is b another is b prime. So, let us say that this is b this is b prime or vice versa. So, in that case you can substitute go back and look at the stress field expression and if you substitute you get an expression like this.

What does it say so what it says that F 1 is positive if b 1 and b 2 they are both positive. The similar dislocation that F 1 is positive that means the force along this direction is positive. Similarly, force along F 2 here along this is also positive. So that means the force is acting along this direction and along this direction, which means you can convert it into cylindrical co ordinate also which can be done very easily.

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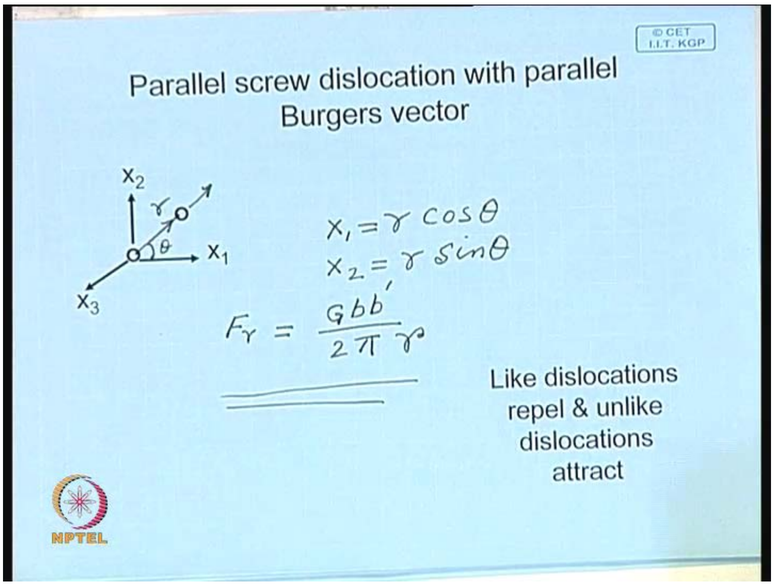

Say, if you take that if you see this distance r, this angle is theta, then you just substitute x 1 equal to r cos theta, then x 2 equal to r sin theta. If you substitute that in that case you will find that the force along this direction, force along that radial direction. This is the only existing force this will be G b b prime over twice pi over r. So, this expression is so simple and what it shows that if this dislocations are alike both are similar character they will repel each other.

But, if one is a positive another is a negative, then the force will acts b is equal to minus b b prime equal to minus b, then the force will act in the opposite direction. So, basically they will attract each other so that means if you assume one is right handed screw, another is a left handed screw. If these two dislocations come meet together if in that case the dislocation will disappear. So, this is one way in which dislocation can disappear as well.

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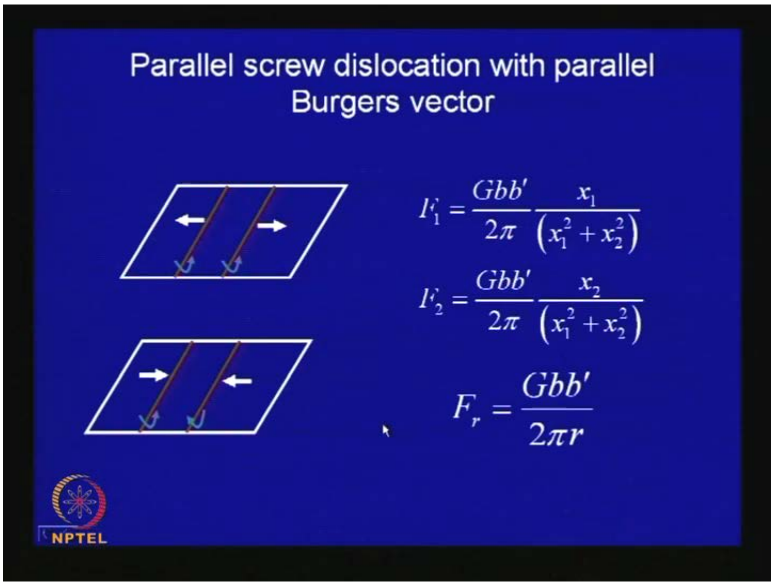

So, this is what we talked about if you have two parallel dislocations, which are alike in that case they will repel and this is the case where this dislocation, so one is right handed screw another is left handed screw. Then there will be a force of attraction they can come together and annihilate it one another.

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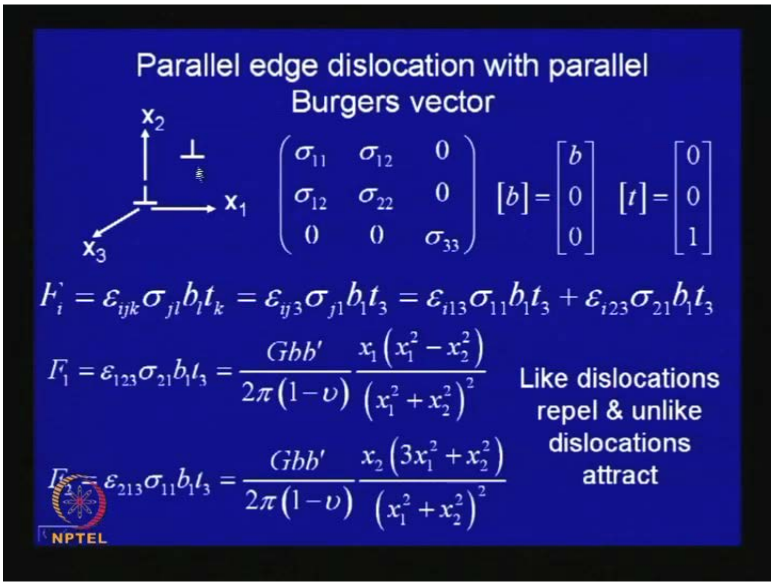

Now, similar calculation in case of edge dislocation will be also can be done in exactly the same way following the that tensor Cartesian tensor convention I just introduce and it is very easy to understand tensor of this interaction and which is shown here. In this slide and here also the nature of the interaction will depend on whether they parallel to each other. Whether the burger vectors them also parallel so that means this is the case where parallel edge dislocation with parallel burger vector. You can do in the exactly the same way if they are parallel dislocation but burger vector is that right angle.

These are some of exercise, which you can try yourself and with is the way in introduce it should not be difficult for you to arrive at this and understand such interaction. Now in this particular case edge dislocation the non zero components of stresses, which are listed over here and here again the burger vector burger vector is along x 1 direction. So unlike that burger vector is along previous along x 3 a burger vector is along x 1 direction. So, b you can be represented as the b 0 0 only b 1 component is a non zero component. Similarly, case of that t it is only the x 3 component is non zero and with that if you subtract and substituting let us say find out a general expression for the i th component of stress if i.

So, you will write this is the overall general, you can mention. Now here t only non zero component is t 3 you have only t 3. So that means k can take value 3, so replace here 3, here 3. Similarly, b can have only value b 1 so b 1 and here also that one is 1, here also it is 1. Now you left with only two suffix i and j, i of force it will denote the i th component of stress. So, you will find out whether i is one or i can have value 1 2 3 three component of force. Now what value can j have now here this j it will depend which are the non zero component of stress. So, j can have value this is already 1. So, j can have value 2 because sigma 1 2 this is the non zero component. So, j can have a value 2. Now, can you take value 3 if you put sigma 3 1 look at this table here sigma 3 1 it is zero.

So, it cannot have value 3, so you substitute back to it can have value 1. So, j can have value 1 this is sigma 1 1. So, you have two possibilities sigma 1 1 and sigma 2 1, which is substituted here. So, this gives i th component of the force. Now, clearly there are two value i can have now, if i can it be 1. Now, it cannot be 1 because i if you say that if it is see I can have 1 because here second part. Here, if you put i equal to one in that case this becomes zero, because epsilon 1 1 3 this is zero. So, this part become zero but here epsilon i 1 2 3 this is equal to 1. Therefore, F 1 will be equal to epsilon 1 2 3 sigma 2 1 b 1 t 3 and you substitute look at that value of stress field and substitute here you get the force F 1.

So, F 1 is the force acting along this direction, this is non zero. Now, similarly can F this i b 2. Now, here if you substitute i equal to 2 look at here if you put i equal to 2, in that case this co efficient epsilon 2 2 3 this is 0. So, this vanishes but here 2 1 3 remains. Now, 2 1 3 look at here, so if you look at this sequence it just the reverse sequence. So, we talked about this 1 2 3. We said that the epsilon i j k is positive plus 1, if this suffix i j k are in the clockwise sequence 1 2 3. Now if it is 2 1 3, then in that case that means 2 1 3 in that case this is minus 1. So, if you substitute here 2 1 3 minus 1, then you get the expressions.

So, there are now only two component of force will be acting here, one is along this direction, which will help it to glide along this whereas, there is a force along this direction, which you know this is not the slip plane. This is the plane in on which it can climb. So basically so this will be ineffectual I mean this cannot contribute to the glide movement of the dislocation but it can certainly help in climb motion.

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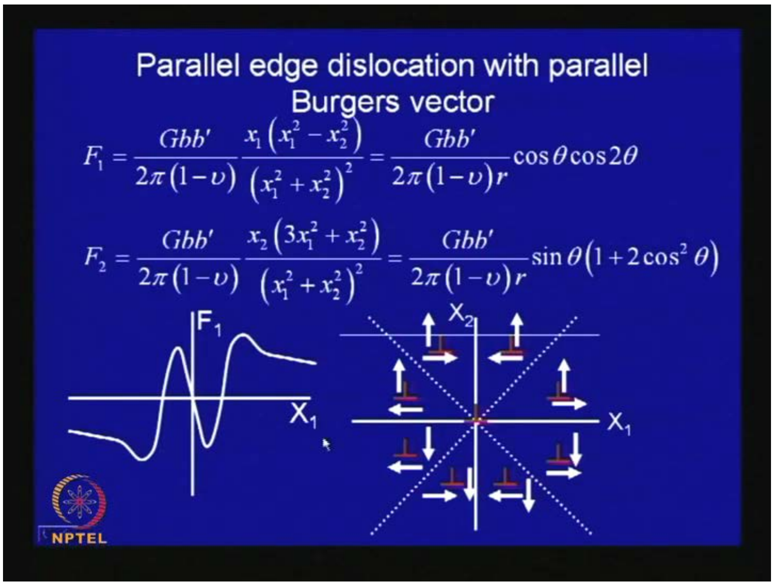

Now, here also if you look at this, let us look at the nature of interaction depending on where these dislocations are located. Because, this force is a clearly a function of because what we can say this are virtually constant. Because we know the burger vector in a face centered cubic crystal the burger vector they are fix this will be so these are all constant. So nature of this interaction depends only on the location of one dislocation with respect to the other. So, that means the relative positions so that means the coordinate x 1 x 2. So, this is and x 3 does not feature here. So, that means along the length of the dislocation the nature of the stress field is exactly same.

Now here also if you do this polar conversion which is easy to understand, so you can do the same thing I am sure that this expression looks much simpler. So, this is inversely propositional to the distance between the two dislocations. So, that means if the dislocation is far apart interaction will be less. Now let us look at this co ordinates say this is a 2D diagram. This is x 1 axis, this is x 2 axis these are the lines where x 1 is equal to x 2 if x 1 is equal x 2. What does it shows let us look at the nature F 1. If x 1 equal to x 2 then F 1 is zero. So that means if a dislocation lies here that is no glide force.

So this is you can say one position of equilibrium. So, that means this point say suppose we take a section here and let us try and understand what is the nature of the force as you move from this point to this, are you come from a distance along this up to this. Now here clearly here you will have the force is equal to zero and if you look at here in this case this force you look at it you know x 1 is greater than x 2, if you are here x 1 is greater than x 2. So, F 1 is positive therefore, the nature of the interaction is one of repulsion. So it is repelling so it is a not like screw dislocation that exactly the nature of the force it can change from repulsion to attraction.

Even if they are of have similar character, even if they have similar character they can change over from repulsion force to an attractive force depending on where this dislocations are located. So, here this is the position of the equilibrium, if you go this side there will be repulsion. But if you come here in that case x 1 is less than x 2. Therefore, the F 1 is negative so it is pointing towards this direction. So if at dislocation is located here there is a glide force and you do not need much of a force to move a dislocation. So dislocation will glide along this and when it comes over here and that case here x 1 equal to zero. So F 1 equal to zero and here if you try to push it here then you will find the force is acting in this direction. So again this will bring it here.

So this is a position of most stable dislocation configuration, if you displace it here it will try to come back to its position. If you displace it this way again it will try to come back to its position of that equilibrium position. So, this is a very stable configuration whereas, this is an unstable position of equilibrium displace it slightly here, this will move this direction and if you displace it slightly this then it will come here. So, this is a unstable equilibrium, so if you do that and make a plot you will get a plot say something like this F is negative very close when this portion F is negative, here F is zero.

So this point represent this again it goes up and then it will go to a distance some where you can find out where it will be maximum. So, basically where it will be maximum at which position of theta or which position of basically, here we say that x 2 is fix at which value of x 1 this will be maximum. You can differentiate and find it out and you will find this is the maximum distance at this is where this is the distance, where F 1 is maximum and this will be symmetric on the either side.

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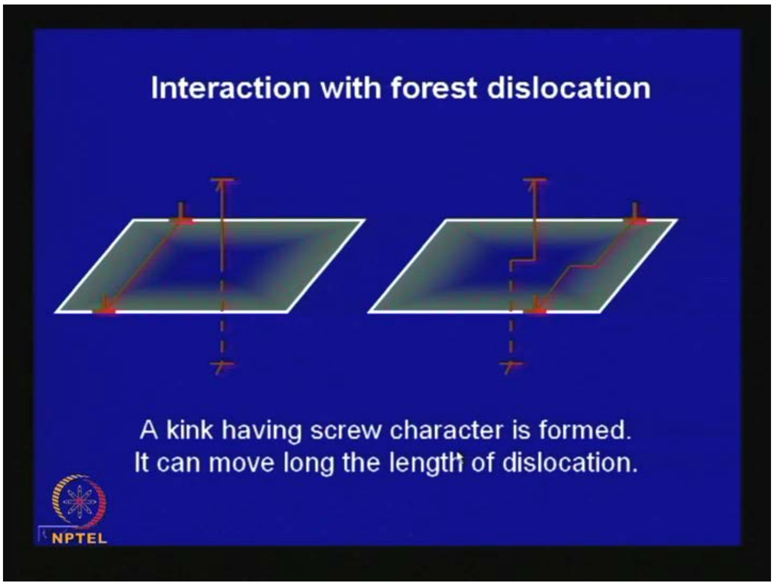

Now, so we have understood so far that since dislocation they have their own stress field so if one dislocation comes close to another. In that case the elastic stress field they will interact with each other. Now suppose what happens when dislocation crystals have several dislocations and say suppose, this is a slip plane in the crystal you have edge dislocations. Now there will be several dislocations, which will be threading like a tree say basically threading through this slip plane. This is perpendicular to the slip plane this is an edge dislocation. So basically we say that when a dislocation will move in a crystal it is bound to come near other dislocation, which are intersecting the slip plane.

So, what happens when such a dislocation, you apply a stress feel here. There will be stress force shear force here on the on this dislocations, when it is moving on this plane this will try and move on this plane. So when interact what happens, which is shown here. when it comes this side this will its burger vector is like this. So what will do it will create a step over here. So look at this is the step over here. So here also similarly, this dislocation will also develop a step like this. Now look at what is the burger vector, in this particular case the burger vector is pointing along these directions and what is the dislocation direction, dislocation direction is like this in this part.

So this portion of the dislocation it has this portion of the dislocation has a character is little different this part this burger vector. This is the burger vector this is the dislocation direction this at right angled, so this is edge this also is edge but this is screw dislocation. So this screw dislocation can move it has the multiple it can cross move on any plane, which contains it can also move in this plane. So this is the type of step, which you can say a mobile it can move along the length of the dislocation and come out of the slip plane. So same thing here also its character is that often a screw dislocation. So this type of the step is called kink and it has a screw character and it can move along the length of dislocation.

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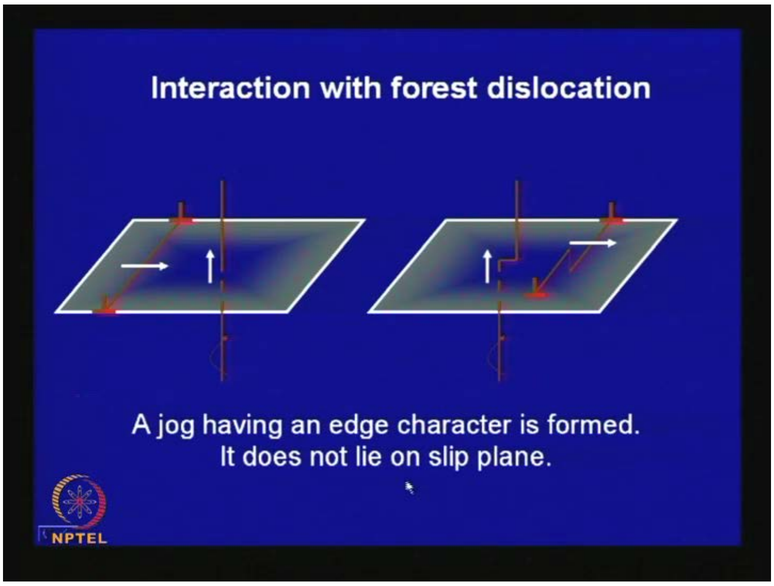

Now, what happens if this dislocations are little different, now in this particular case this is an edge dislocation, this is the screw dislocation, this is the burger vector along. Now here if it moves it passes through, then what happens? Say this goes this side, this comes this side. So, here this will try pushing a part of dislocation, part of this dislocation on the upper plane. So this moves to their upper plane. Now look at it, this is this dislocation is still lies on the previous slip plane whereas, this dislocation has moved to a plane just above it. So, they are no longer on the same slip plane, and here is another dislocation which is lie this here, and what is its character? Burger vector is this; burger vector remains same along the length of the dislocation, it does not change unless another dislocation meets.

So, basically here so here also it is perpendicular. So, this also is and has an edge character. So, this type of step is called a jog and this jog you know if it is a slip plane it can move on this perpendicular plane perpendicular to this. But if you look at say suppose face centered cubic crystal. In a face centered cubic crystal the slip planes are not normal to each other. Slip planes say if it is one slip plane which is 1 1 1, another slip plane which is also has to be 1 1 1, that will lead to intersect at an angle.

So, if a jog forms here if there is a perpendicular dislocation if a jog forms here then that jog will not lie in a common any 1 1 1 type slip plane, which is a normal slip plane in FCC. So, this will act an as a obstruction to the movement of the dislocation and this jog dislocation can nevertheless move a vacancies can migrate to this jog. Then this portion will in non conservative manner whereas, this will be the glide normal glide motion.

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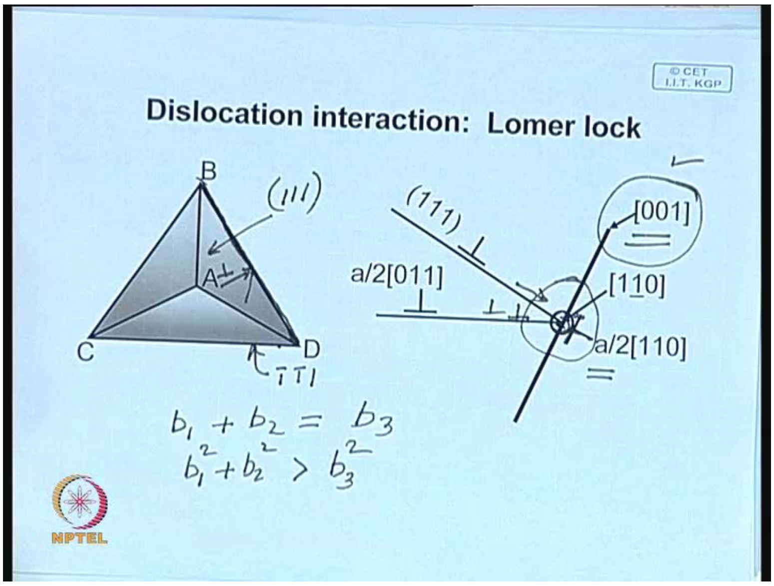

There is several interesting dislocation dislocation interaction that can take place. If we consider say let us say if we consider face centered cubic crystal say a dislocation moving in one slip plane, if it comes and meets another dislocation act along a line, where this slip planes meet, which is shown over here. This is a plane 1 1 1. Here is a dislocation although have represented it by edge it is not necessary edge dislocation we can consider as suppose this is the mixed dislocation. So although I mean just to represent it has been like this and if it is moving along this it comes here another dislocation, whose burger vector is this is also moving along this and when they meet together what happens.

So, what we can write so that means two dislocations say if b 1 and b 2 they meet. So they will vectorically add up and produce another dislocation with the burger vector b 3 and this will be energetically favorable, if we check b 1 square plus b 2 square, which represents the energy of the reacting dislocations. The two dislocations if this is greater than b 3 the product dislocation then this is energetically favorable. This reaction will take place and when this dislocation reaction takes place this dislocation will lie along the line of intersection that means suppose, say this is plane suppose this is the plane 1 1 1 and this is the plane.

Another plane say the bottom one this is the plane let us say another 1 1 1 plane. Say let us say 1 bar 1 bar 1 another plane and they meet along this line B D. So, a dislocation which is here moving along this and dislocation, which is moving in the bottom, plane B C D and they together they meet here. So, then the two line react the dislocation line will lie along B D. So, which is shown here this is dislocation which is lying along this direction, which is perpendicular to this plane. Say suppose it need not be this is a tetrahedral. So this is the direction that is line of intersection of 2 1 1 1 plane it is lying along this.

So, this will have a burger vector, which you can calculate and then if they not along this, so that means if it is a mixed dislocation or an edge then it will have a specific slip plane, which can be calculated and if you find that this slip plane is not the normal slip plane. Say suppose if it is comes out the plane on which this dislocation line and the burger vector lie this is lie on this particular plane, which is not a slip plane. Then we say that this is a dislocation lock and this type of dislocation lock two perfect dislocation moving on two intersecting 1 1 1 plane.

If they interact they develop a dislocation lock which is immobile and this will not allow so this will have a stress field surrounding it. So once this lock is formed this will not allow the other dislocation to pass through this. This will have a stress field this will repel we will stop here the other dislocations will not be free to move. So this is the way a crystal hardens during the plastic deformation and which is shown over here.

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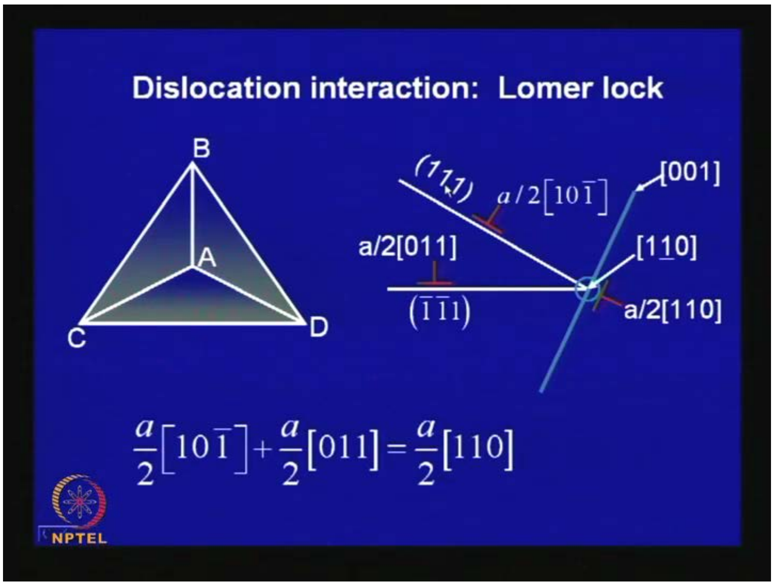

So, these are the two plane this is 1 1 1, this is 1 bar 1 bar 1 and you can write down the burger vector of this calculate, the burger vector of this particular dislocation a by two 1 0 1 bar, which is shown over here and this is a by 2 0 1 1, which is shown here. If they two add up then this is the burger vector of the resultant dislocation. Now here you can clearly see if you find out the energy of this dislocation is a square over 2. This is also so this type of the dislocation if you try and check weather this dislocation is energetically favorable or not and what it will find out that this dislocation is a square by 2, this is also a square by 2.

So total energy is a square whereas, the dislocation energy is a square by 2, which is certainly less so this is energetically favorable. So this reaction will take place and this and you can then find out what is the line of intersection? Line of intersection of these two plane is 1 1 bar 0, if 1 1 bar 0 and this is 1 1 0. So this character this is an edge dislocation the Lomer lock, which forms this as an edge character. Because this is perpendicular to this dislocation direction burger vector is perpendicular to the dislocation direction and on which plane does it lie, clearly it is 0 0 1.

So, which is not a common slip plane in the face centered cubic crystal. So, this acts as a dislocation lock so this dislocation will inhabit for the movement once this lock is formed, this will inhabit for a movement of dislocations on this plane. So this is one mechanism of strain hardening dislocation mechanism which explains strain hardening behavior of face centered cubic crystal.

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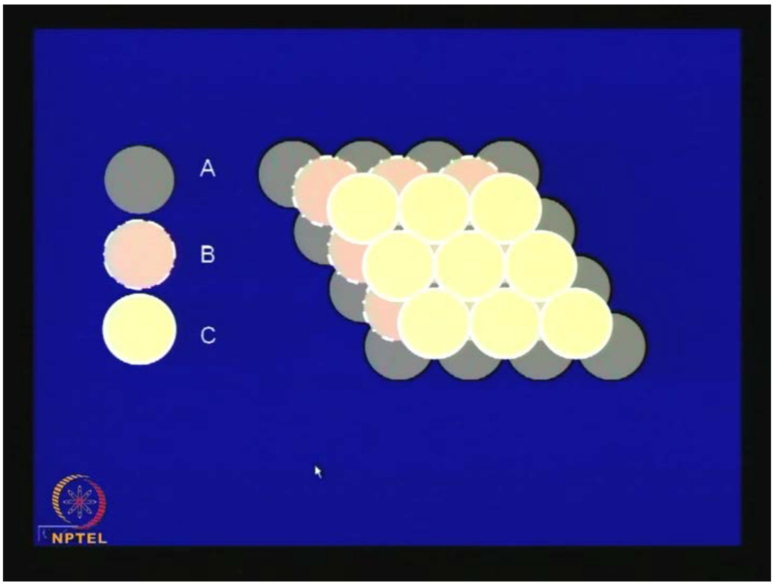

Now, we will let us look at the way the atoms are arranged and depending on that arrangement of atoms can is there any other types of dislocation that we can think of so far, dislocation that we have considered is something like this. This is the closed pack clean of the face centered cubic crystal. So all these atoms they are closely packed and these directions are this is a 1 1 1 plane and these directions are 1 1 0 directions. These are diagonal face diagonal direction and the next layer which will go and occupy the one of this sites, if you look at there are two site if this is a layer A.

This is a site B this is site C and when the next layer comes it occupies that is a B site but it blocks the C as well part of the C is also blocked and it cannot occupy the C site C site is the site and then when the next one goes it occupies C site. The face centered cubic; this is the way the dislocations are arranged. Now what happens if this sequence is disturbed in face centered cubic crystals as this planes 1 1 1 planes are arranged in sequence A B C A B C like that.

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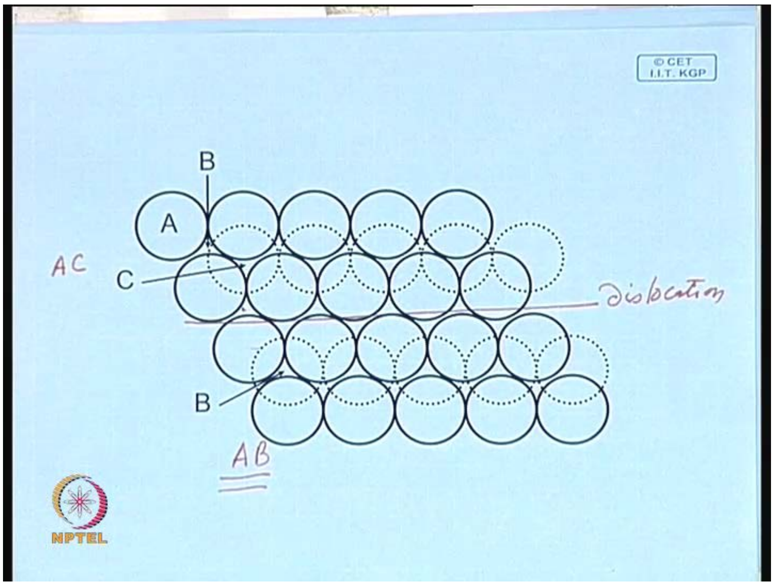

Now, what happens if this is disturbed which is shown over here. Now look at this here say this is the A site and now suppose that the B layer has also been. So these are B the B site, now what happens if from this is the B site so B site it has to go from here to here, so this atom this layer earlier was occupying is having it occupied this. If you draw the circle you will find this will touch this as well for draw a same circle, you will find this will touch this as well. Now if this moves from here that means next row of atom if it moves here. Then what happens a gap is created and a gap is created and thus that means this is the line type of line defect, there is gap is created on this particular plane and so this is the dislocation.

There is a dislocation here. A dislocation is created here and also over A here the sequence also breaks. After A this is the C whereas, this part after A the sequence is B. So, in this on the two sides of this defect, the sequence the way the 1 1 1 planes are arranged that sequence is disturbed, which is very easy to understand and is this energetically favorable and this is to understand that imagine visual visualize like this you have an atom here. Now you have two sites here. If you take a hard sphere put this atom here. Now next layer of atom if you put it here the next one immediately you would not be able to put in that position, you have to see this a site here immediate, so this one site, this is another site.

So here you cannot put if you put it is coming here. So part of this site is blocked. So similarly, here also you cannot put would not be able to put an atom if you put it will come here. So that means let us say if this is the B site. Now if A B sites a perfect dislocation it has to move from this position to this. This is the B site; this is the next B site. So this is burger vector 1 1 0. Now that means what it has to do this atom will move up the plane and again come down, which is little difficult energetically. Whereas, what it can do it can pass through the valley like this and come like this and this is what has been done in the figure, which have just shown.

So you look at this figure here the this is what has happen this row of atom was only attaching this occupying this site, this has move to C site and it is create a dislocation a defect over here.

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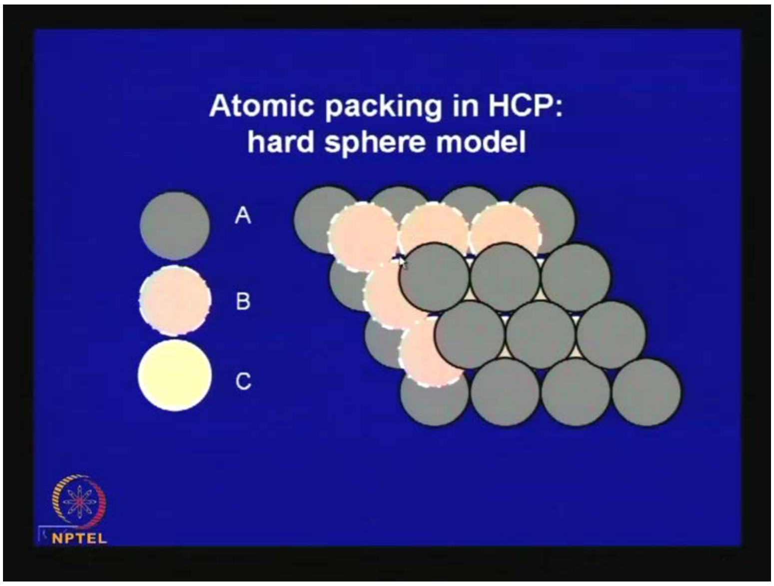

And in that case so look at what is this it will be interesting to recall, what the packing sequence is in a hexagonal closed packed structure. This is called hexagonal closed packed structure, here what you have the C layer is not occupied. The sequence is A B A B A B that is the way so here you can see through you can see that the base that backgrounds color this background color is visible here. So that means this layer is not occupied.

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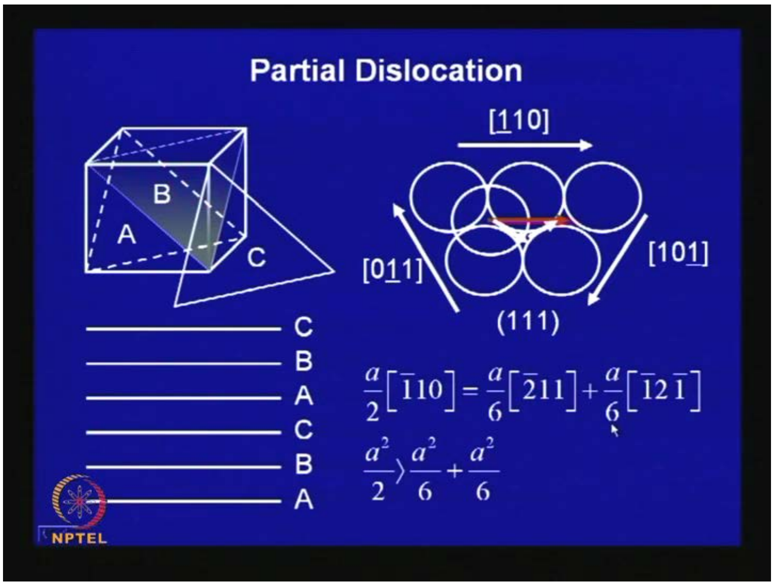

Therefore, and let us see what has happen over here if you look at this. This is the way this dislocation I mean atoms are arranged in the closed packed 1 1 1 plane. This is the closed packed direction. I will leave it to you to find it the dislocation direction, which is written over here and then what is this direction. You will find out that this direction is a direction of 1 1 2 type direction. So basically this direction is 1 1 2 type of direction and here what you we have done is say suppose if this is the burger vector, which is a by 2 1 bar 1 0. This split up into two burger vector say part of the crystal is this part of this another site, there is another dislocation.

So, this is the perfect dislocation which is this, this we called the perfect dislocation. We call it does not disturb the packing sequence. Whenever this type of dislocation is there then packing sequence remains intact. But when you have this kind of a disturbance this splits into 2 1 1, two type of dislocation and you can find outs the magnitude. Magnitude will be a by root 6 and once you do this and then you find out the energy. You will find that the energy there is reduction in energy. Therefore, this dislocation is energetically favorable and using that hard ball concept also, it is upper end that this kind when it when this atom moves to the valley the movement is easier.

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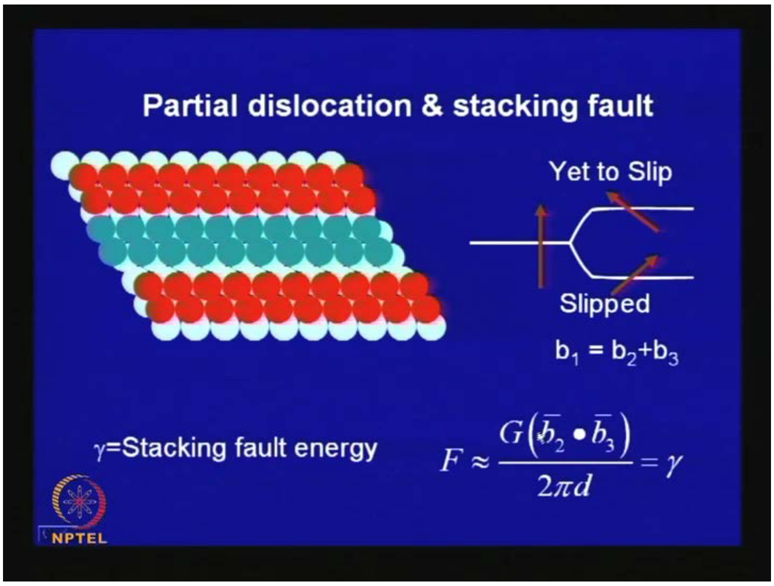

Now, let us look at what happens? So, this is a picture what happens, say this is a say this is A, this is B, that is B red is B. A part of this dislocation has taken C layer so and here. Then here there is a gap so you have a dislocation here. You have a dislocation here. So these are the partial dislocation, which is shown over here. These are the two partial dislocations and say suppose somewhere here this site they may join together. So this may be a perfect dislocation, which is shown over here. So this is a perfect dislocation this part this stack stacking sequence is not disturbed or whereas, here this stacking sequence is disturbed, only in this part that stacking sequence there is disturbance in the stacking sequence.

Now this type of regular fault where the stacking sequence is different is called stacking fault. So this is this has two dimensions fault exist over a particular area. So, this has 2D two-dimensional, it has two dimensions it has length it has width and this width of this. You cannot say that these are the distance between the two partial dislocations and this is will be very easy to calculate from the dislocation dislocation interaction. In fact we can approximate this in this particular case we can approximately say that the force acting between the two is equal to G the dot product of these two burger vector over this and this is equal to because it creates a new defect which is called stacking fault energy.

This is has a new surface visualize as a new surface is being created and whenever a new surface is created there will be an energy associated with it and we call this energy stacking fault energy and it is possible to calculate this stacking fault energy. We will see later how dislocation you can see in a microscope and in a transmission electron microscope and these partial dislocations can be seen and if you can find out the distance between the two partial it is possible to calculate this stacking fault estimates the stacking fault energy.

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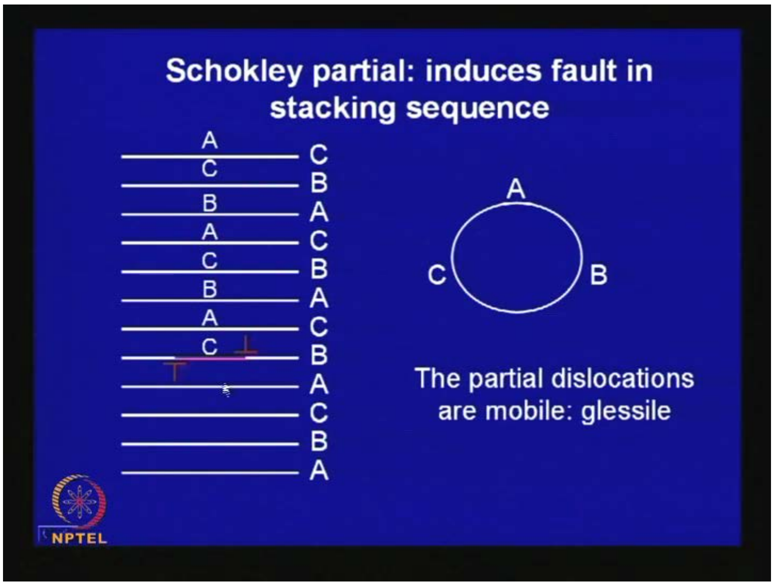

To sum up it is something like this. This is the type of sequence A B C A B C, this is the perfect I mean where there is no stacking fault and whenever suppose this particular case here, this part of the crystal it has gone through move through one partial dislocation. That is a by 6 1 1 2 type, which is shown over here. So, in that case the B moves to C, if B moves to C, C will move to A, C will move to A. Similarly, and this sequence continuous in that direction, so look at over this you have A B C A C. So, you can see here it is C A C. So, here the sequence is something similar to a hexagonal closed pack structure the sequence is disturbed.

Therefore, we call this a stacking fault, and it comes is a two partial dislocation. So, one is a leading dislocation, this is a trailing dislocation, and we say that this is here this stacking fault that is a disturbance in stacking fault and we call this as say 2D or surface defect. And next class we will build upon importance of it is quiet important to know the behavior deformation, behavior of face centered cubic crystal is strongly depended on the type of that stacking fault it has. And say for example, the cross slip will become more difficult, if the stacking fault energy is low and this partials are far apart. So unless these partials there is a constitution on be able to move at I mean cross slip. So this acts also to the strain hardening a fix strain hardening behavior of a face centered cubic crystal. Thank you.