Principles of Physical Metallurgy

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Lecture No. # 10

Crystal defects in metals

Good morning, today we begin a new chapter. And this chapter, we shall learn about some of the defects which are present in crystals, particularly with respect to metals. And last class, we had seen that that process of deformation takes place in metals by process of slip and (( )). And we also calculated that if the crystal is perfect, it does not have any defect, in that case the stress required to (( )) slip in a crystal is very high. But in reality, the metals deform at a stress much lower than the ideal resolve shear stress. And the reason for this lies and the fact that crystals are never perfect, it has defect.

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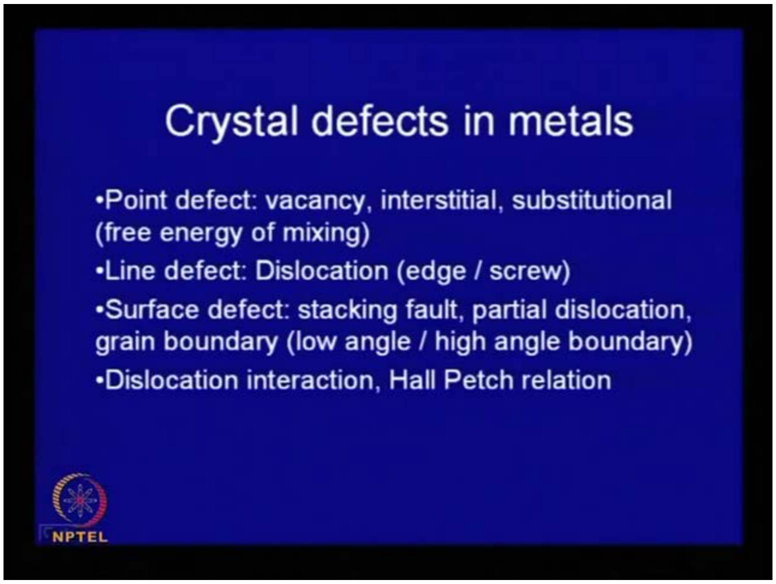

Crystal defects in metals

- Point defect: vacancy, interstitial, substitutional (free energy of mixing)
- Line defect: Dislocation (edge / screw)
- Surface defect: stacking fault, partial dislocation, grain boundary (low angle / high angle boundary)
- Dislocation interaction, Hall Petch relation

And this chapter, we shall learn about the types of defects which are present in metals, metal crystals and how and what is their effect on properties.

So broadly, we will consider point defects primarily some vacancy, some interstitial atom, some substitutional atom, we will also try and find out why it is necessary to have vacancy in metals. And there is a relationship I mean how much energy is needed to create a vacancy. We also we will look at some line defects, they are known as dislocation. They are two broad types of dislocation edge and screw. We will also learn about surface defects, like stacking fault, and what causes stacking fault. So that means this is also associated with formation of a different type dislocation called partial dislocation. We will, we have already talked about grain boundary. This is also a type of defect. There are different types of grain boundary. We will try to know about it in a little more details. We will also look at dislocation interactions and some of the dislocation mechanism for strengthening. We will look at the Hall Petch relationship, which defines the strength of metal as the function of its grain size.

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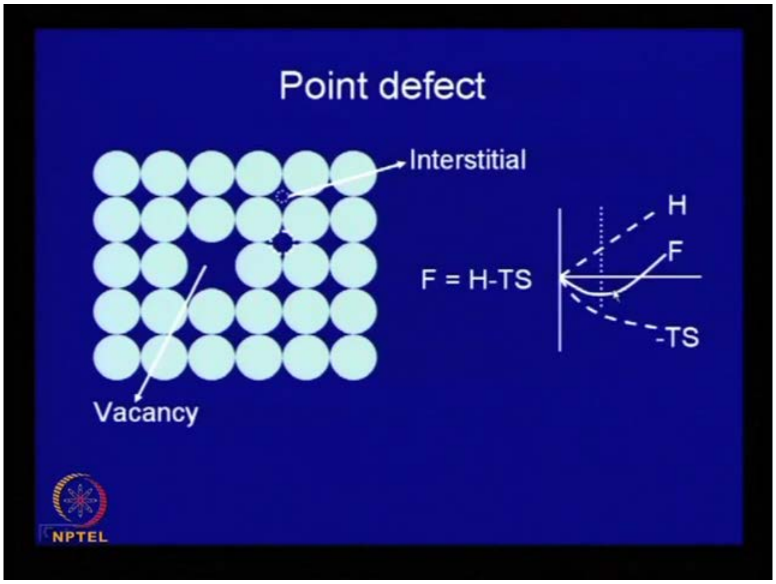

Point defect

Now let us look at point defect. What is it? Now one of the common point defect is vacancy. Say crystal is an array, periodic array of atoms, which is shown over here along this line. But often it so happens some of these atomic positions are not occupied by atom like here; this is a vacancy. This is a point defect. And sometime, we try to push another atom that is possible when we do a line, if an atom is very small, it can be accommodated within this interstitial space, the gap within the lattice. And if the lattice, this atom is large, so something like here, it will try to push these atoms as part and cause a strain field. Now why do we have vacancy in crystals? Now this is we can look at it like this. We can assume that vacancy to be spaces and say basically we can think like this that this system is a mixture of atom and vacancy. And as the concentration of vacancy increases, definitely the stability or energy of the system will change.

And we know that stability of any system, it has been introduced it defines in terms of free energy, which is written like this. Free energy is equal to an energy term – internal energy H or enthalpy, minus T is the temperature times entropy. The entropy is the major of disorder. So basically, what we can look at it that if this vacancy they are arrange, they can be arrange at random and this causes a disorder in this structure. You increase more vacancy, you increase the disorder, so therefore the disorder increases the entropy of the system increases. And the basically, if you look at the total overall that energy that nature, if you want to create a vacancy, you have to give some energy. And if you want to create more vacancy, you have to spend more energy, so H is moving like this. And this entropy increases with the disorder, but overall effect here, it is minus T S. So basically this is negative, this decreases like this; temperature times entropy decreases like this. So therefore, the total energy of the system will have a nature like this. That means, this axis is an energy; this axis is the concentration, so there is an equilibrium some concentration of vacancy.

This determines if the vacancy keeps on decreasing the system become more, a vacancy keeps on increasing, the free energy decreases and it attains somewhere minimum over here. So this is the stable configuration. So this is one can say that this is the equilibrium concentration of vacancy in the system. Now it is possible to calculate or find out the concentration of the vacancy in a lattice. And here this is the a very simple case where you can apply the principle of statistical thermodynamics. Now entropy one of the major factor contribution of towards entropy is how these vacancy is arrange in the lattice. They will be arrange in random, arranged at random. So, you can think about two species, one is the atom and another is vacancy. And if there are n sites, n n total number of site out of this parts n is atomic site side occupied by atoms and n v is the site occupied by the vacancy. And total number of sides is equal to n plus n v.

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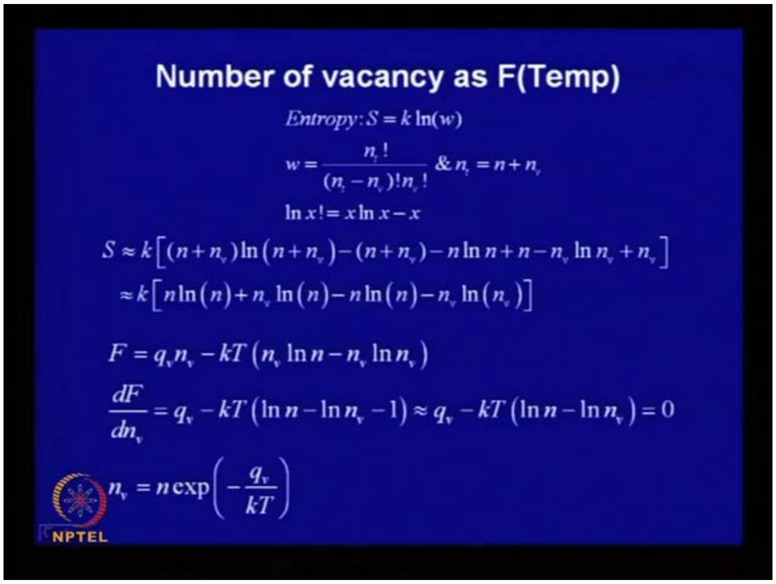

Number of vacancy as F(Temp)

$$Entropy: S = k\ln(w)$$

$$w = \frac{n_t!}{(n_t - n_v)!n_v!} \;\&\; n_t = n + n_v$$

$$\ln x! = x\ln x - x$$

$$S \approx k\left[(n+n_v)\ln(n+n_v) - (n+n_v) - n\ln n + n - n_v\ln n_v + n_v\right]$$

$$\approx k\left[n\ln(n) + n_v\ln(n) - n\ln(n) - n_v\ln(n_v)\right]$$

$$F = q_v n_v - kT\left(n_v\ln n - n_v\ln n_v\right)$$

$$\frac{dF}{dn_v} = q_v - kT\left(\ln n - \ln n_v - 1\right) \approx q_v - kT\left(\ln n - \ln n_v\right) = 0$$

$$n_v = n\exp\left(-\frac{q_v}{kT}\right)$$

So with this kind of case, if you try and arrange these two species, so then what you will get the way you can arrange them is given by this. This is the case of simple arrangement permutation, combination problem. So if you have this is the total number of atom, which is at can be arrange n factorial n t ways. And sees these atoms there in distinguishable, so this is n t minus n v – is the number of vacancy, this is the number of atoms, so they are totally distinguishable. So they are number of arrangement reduced by this factor, factorial. And this is the way this number of vacancy is also in distinguishable. And here that entropy has a relationship with the way this arrangements can be made and which is shown over here. Entropy is equal to k times log to the base e ln ln w, that means way these arrangement can be made. And usually, these numbers are very large, these factorial whatever we consider is very large. And there is an approximation, approximate way of calculating such large factorials which is known as (( )) approximation and using this approximation one can write that ln factorial x equal to x ln x minus x.

So if you apply these approximation, and then you can derive an expression for entropy because of this way the vacancies are arrange and which is shown over here. And with a little algebraic simplification and with some approximation like this n is much larger than n v. So, in cases, wherever some cases you can n plus n v can be approximated as n. So basically with this, it is possible to show that this entropy is equal to this and which here this, this gets cancelled. So therefore, this is n v ln n minus n v ln n v, so which is written here. So therefore, you can this is the entropy part of the free energy expression, and also to create a vacancy you need to give some amount of energy which is q v. To create one vacancy, you have to spend or you have to provide necessary activation, and this activation energy is q v. So this is the total expression for F and you can try and minimize find out at what value or what magnitude of n v, F is minimum.

So the best way you can do it, you differentiate it with respect to n v which is shown over here and then equated it to zero. And therefore, it is possible to show approximately the number of vacancy will be equal to n exponential q v by k T. And may be, you can try as an exercise, where T is the absolute temperature, k is the Boltzmann constant, so this is the Boltzmann is known. And suppose for a metal, say suppose take copper and you will find that you try and find out it’s a number of vacancy and say this can be around 100 kilo joules per mole, q v to be around 100 kilo joules per mole. And therefore you can try and find out and one bcc of say metal copper, what will be the number of vacancy at say temperature, room temperature and another at say 1000 degree Kelvin. And you will find out, since because of this exponential nature of this temperature dependents, you will find that vacancy at higher temperature will be several order of magnitudes more than that at room temperature.

Now there can be another type of a point defect we can think about, we often makes metals, so which is known as alloying. And primary purpose of alloying is to improve the its properties. Like we know the silver is very soft, if you makes it with a little amount of copper, it makes it hard, so which is actually known as sterling silver. And when you mixture these atoms when thus thus atoms go, now which is pictorially shown here.

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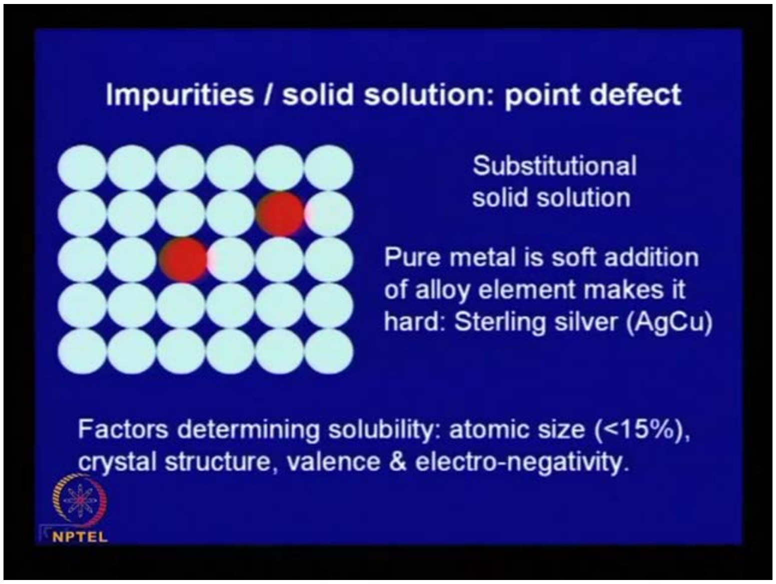

Impurities / solid solution: point defect

Substitutional
solid solution

Pure metal is soft addition
of alloy element makes it
hard: Sterling silver (AgCu)

Factors determining solubility: atomic size (<15%), crystal structure, valence & electro-negativity.

So they can go there are two sides basically. See one here, say suppose this is a metal A and this is red is metal B. So if you add a metal B some amount what it can do, it can replace some of these atoms from its normal side, and it is substituted by metal B. So this type of, this also we can consider because that arrangement disturbed that we (( )). So this also is a defect, this is also a point defect. And we call this type of defect, you can say that this is a substitutional impurity atom, and we consider it is an impurity atom. And we call this as a substitutional solid solution.

Now pure metal has been mentioned is soft, an addition of alloy element makes it hard. This example like a is that of sterling silver. Now what are the factors which will determine how much atom you can take a particular lattice can dissolve how much amount of another metal. This will primarily determine by these certain properties of the two, or certain characteristic of these two metals. And these factors which are listed here, so one is atomic size. If this atomic size is nearly same, you will find the very large amount of you will find that the two can makes impossibly all proportion. All say the large amount of second element can be taken into solution, so which is as I shown here. So this atomic dimension is same, so there is no lattice distortion. So in this kind of setup a large amount of second element can be dissolved in the matrix, but which is very rare, always you will find some amount of difference in size. So when a larger atom is put over here, it will try and displace, generates it strain. Similarly if this atom is little smaller, this atoms also get pushed, so here also the lattice around the atom will get little disturbed. So there will be some amount of stress field surrounding the solute atom.

Next factor is the crystal structure. So if the both crystal structure is similar, then they can have large amount of solubility. Like you say that case of silver copper; silver is in fcc, copper is also fcc. So here there is an substantial amount of solubility, but take the case of let us say R n. R n is the bcc structure and say suppose if you makes it you add some amount of nickel to it. Nickel is fcc or some amount of copper to it, copper is fcc. So here definitely because of the difference in crystal structure, they will have limited solubility. Another important factor is the valance, if the valance are difference in that case, it there will be a tendency to form compound. So if the two element valance are different, so instead of forming a random mixture of these two, you will try to form an order (( )), in extreme case it can form a compound.

Similarly, electro-negativity is also quite important. And basically, if we look at the molecular structure, I mean if we can extent it to solubility liquid phase. We know very well water molecules, they are polar; and therefore it can dissolve any other polar molecule. So that has to be a some amount of similarity between the two, so water can makes with let us say some other polar molecule say like say it can dissolve possibly that acetic acid. But if you try and mix with octane or petrol or this kinds of where which are not polar, they on to makes together. So situation is something similar in solid as well. The two species should be nearly identical then only they will they can one can dissolve the other.

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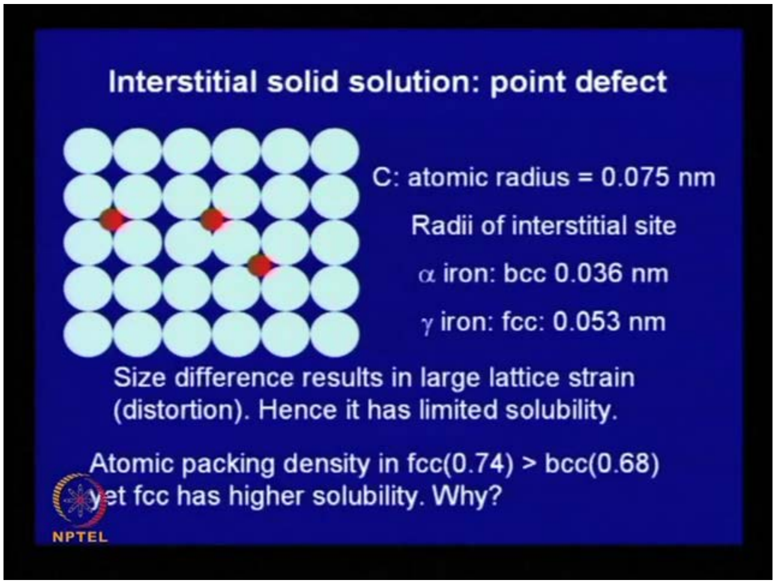

Interstitial solid solution: point defect

C: atomic radius = 0.075 nm

Radii of interstitial site

α iron: bcc 0.036 nm

γ iron: fcc: 0.053 nm

Size difference results in large lattice strain (distortion). Hence it has limited solubility.

Atomic packing density in fcc(0.74) > bcc(0.68) yet fcc has higher solubility. Why?

Next we look at another kind of mixing or the way these impurities can be present in the lattice, which is shown here. This is called interstitial solid solution; this also is a case of a point defect. Say suppose the second atom is very small, they can be it can be accommodated within the lattice. So in that case, we find you know to put it here, definitely very rare cases I think we did some of these solve some of these exercise. Say let us look at a case of iron lattice. Iron exist in two different crystalline form. At a low temperature or room temperature iron is a body centered cubic, and body centered cubic structure has certain types of interstitial sites, and face centered cubic structure has also similar interstitial sites. And dimension of these, I think we did some calculation, some exercise were given. And if you look at that, you will find that atomic radius of carbon atom is 0.075 nano meter. Whereas, if you try to calculate the radii of interstitial sites of the bcc iron that is alpha iron, this is of the order of 0.036. There is a large difference so, if there is a bcc lattice, if you try and push this here, there will be large distortion around the place. So this put a limit, I mean so that means whereas if you look at the other one face center cubic crystal, the radius of this interstitial site is much larger 0.053. It is substantially larger than this, but still it is smaller than the radius of carbon atom.

So therefore, even if here, a carbon atom goes into the interstitial, it will cause some amount of lattice distortion. So therefore, interstitial solid solution definitely there will be some limit to solubility and this will be determine, it would be primarily depend on primarily depend on the atomic size or size difference. And it will be interesting, I think you can again go back to your earlier lectures, and look at say we did calculate atomic packing density for face center cubic crystal. Here the packing density is 0.74, whereas bcc the packing density is 0.68. So yet face centered cubic crystal has higher solubility of carbon. Why? I think apparently this may look like a (( )) that if we look at that little more carefully into the way these interstitial sites are present in bcc and fcc.

So basically, bcc may be the packing density is little less, but what is more important, the dimension of these interstitial site. The octahedral site, you try and calculate in case of which is little larger. So, it will be the atom will primarily, I mean try to carbon atom will try to go into the octahedral site, which is bigger than tetrahedral site. And if you try and calculate these octahedral site in fcc and in bcc, you will find the octahedral site is bigger in fcc than in bcc. So but bcc does have a another tetrahedral site also which is much larger than fcc, but it is size of the tetrahedral site is smaller than octahedral site.

So therefore, the solubility of carbon in alpha iron is very limited. And as we go along, we will find that gamma iron which is on high temperature phase can dissolve up to around depending on temperature up to two percent carbon whereas solubility of carbon in alpha iron is 0.2 percent. So substantially several order of magnitude lower.

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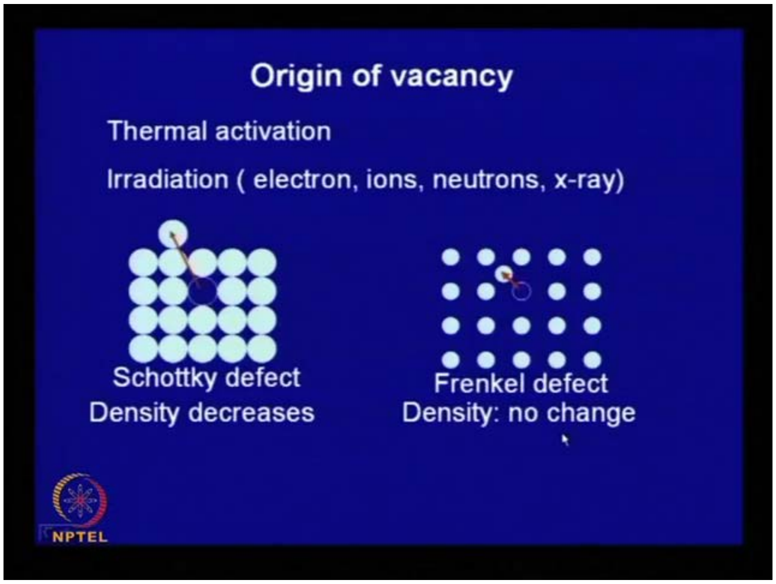

Origin of vacancy

Thermal activation

Irradiation (electron, ions, neutrons, x-ray)

Now let us look at origin of vacancy. So, obviously when we calculate it that number of vacancy which you can get under equilibrium, at a particular temperature. We implicitly assume that to create a vacancy you have to give some amount of thermal excitation. So thermal activation is one, another you can (( )) this metals with high energy particle like electron beam, ions, neutrons or x-ray. In that case also you can, you will be able to push an atom from may be from here to here. So this cases this is the way from if you bombard it with an atom or give some thermal activation one atom, it moves from the center it comes to the surface. This type of defect is known as Schottky defects and in this case you can easily see that the when this atom comes here apparently looks its volume is increasing, so that means it density is decreases. So therefore, this could be a method of finding out the vacancy concentration in metals.

Let have sometime we will see how this can be determines. So looking at this mechanism of formation of vacancy it says that one way of measurement could be density. Another similarly, you can also see there will be some change is in lattice parameter also, dimension also can change. So form that x-ray also that is possible by calculating lattice parameter, lattice parameter also you will get some idea about the vacancy concentration. There is another way a vacancy can be created, you can try and push an atom from its normal site to the interstitial site. This is called Frenkel defect. Here of course, overall way it is form you find that over all there is no change in volumes. So therefore there is no change in density, but definitely there will be lattice distortion. But obviously the interstitial sites are much smaller, you need much higher energy to create this kind of defect.

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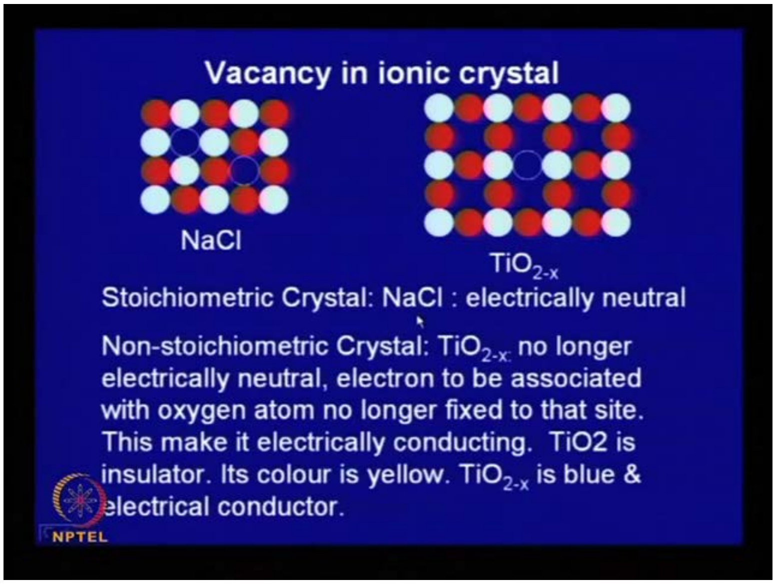

Vacancy in ionic crystal

Stoichiometric Crystal: NaCl : electrically neutral

Non-stoichiometric Crystal: TiO_{2-x}: no longer electrically neutral, electron to be associated with oxygen atom no longer fixed to that site. This make it electrically conducting. TiO2 is insulator. Its colour is yellow. TiO_{2-x} is blue & electrical conductor.

Now if you have vacancy in ironic crystal situation is little different. Say basically, you can have two kinds of ironic crystal say one where Stoichiometric, that two both positive and negative iron. They are present in equal portion, therefore overall it is neutral and exactly like Na C l; valance of sodium is one, plus one and chlorine is one minus. So therefore, this has negatively charged ion, sodium is positively charged ion and their attraction is the main bonding strength. And here pictorially it is shown over here. So if in a lattice, if you have chlorine ion missing, so that means if the balance that overall electro negative or charge of the material. So therefore, to compensate that another sodium atom should also to displaced. So this is the pair of vacancy. So this is what happens in case of stoichiometric crystal like sodium chloride, these are electrically neutral. There are many cases non-stoichiometric crystals like one example, which is shown over here, this is titanium dioxide.

So it is normally, chemical form of T i O 2, that very often you will find there are number of there is not enough oxygen atom in the crystal to make it neutral. So in general, you can write this chemical formula of this type of non-stoichiometric crystal like this T i O two minus x two minus x. x of course will be very small, so in that case what is show that this type of crystal will be no longer electrically neutral.

And this change is the characteristic depending on the magnitude of x, it characteristic, it properties, particularly say it electrical properties or it optical properties will change significantly which is shown over here. Say in this case, one of these oxygen atom here is missing. If that one oxygen atom is missing the oxygen was lightly took here, or take to electrons here from titanium. Basically, these two electrons is an excess, so basically this electron which actually should have been long to this atom is now free. And that is shared by all, so because of this, this titanium dioxide when the oxygen diffusion.

It is not a stoichiometric, exact stoichiometric relationship it follows. In that case, it will exhibit conductivity, electrical conductivity; say if it is pure T i o 2, it is insulator, but in a normal cases, it is not an insulator; say if it is oxygen deficient, it is not an insulator. And pure T i o 2 you know, its color is yellow; it has yellow (( )), whereas if you heat it, you will find or you can create this some of the oxygen vacancy, and then it turns blue; and this is relatively better electrical conductor. So that means, vacancy changes the properties of material. Now after this, let us look at line defect; so dimension of a point defect means, it is a dimensionless say, only (( )) is associated or represent it, you can visualize it that it exits at a point in the crystal. Now a situation is little different. We calculated that if a crystal is perfect that in that case it is c s (( )), which is (( )), which is required to (( )) have to create a slip statement the crystal is almost of the order of a shear modulus or say a shear modulus over 50 or over 100 around that; which we do not get in a real crystal. And reason that we do not get is, because the crystal contains a defect called dislocation, and this is a line defect; it demarcates to boundary; it is a boundary between the split and yet to split region.

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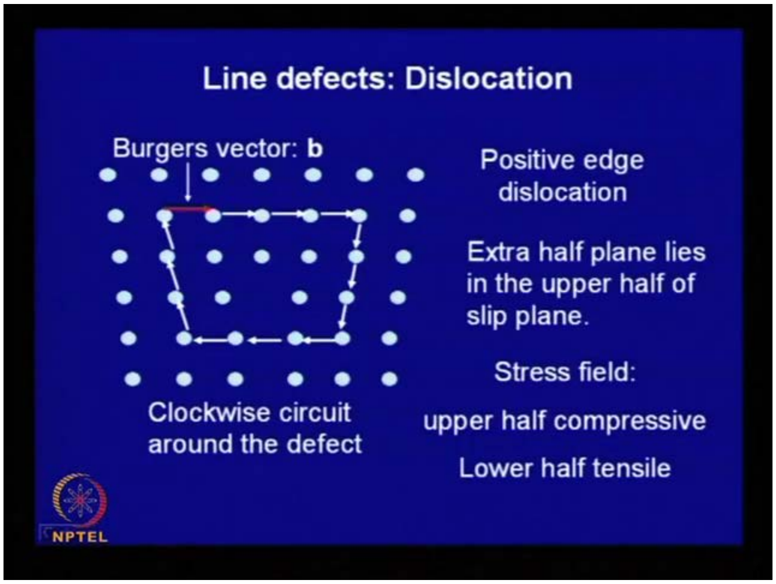

Line defects: Dislocation

Positive edge dislocation

Extra half plane lies in the upper half of slip plane.

Stress field:

upper half compressive

Lower half tensile

Clockwise circuit around the defect

Now, let us look at the atomic structures, around dislocation possible dislocations, which is shown here. This is a type of arrangement, so this a crystal, so this is a periodically arranged, so this atoms are arranged along it is a 2D crystal say, arrange along this line, this is a perfect arrangement. Now, look at it over all, what you have? You have a missing plane here; in that case, lattices will be little distorted something like this; this (( )) distortion actually represents a kind of a stress field say, it is an indication of a stress field, the lattices strain. And if you try say and this line this point which represents a line, and this line is called dislocation, and this type of dislocation is called (( )) dislocation, which you can visualize the dislocation to be in a crystalline, in a crystal lattice term, in a extra plane of atom here. And here you try to describe close this atom to atom a circuit, it is a clockwise circuit, if you want to plot here. So you move three distance this side, three distance here, three atomic distance here. So three atomic this side, three atomic and opposite direction, and here three this way down, three atomic space up to come, to reach over here. So, what you get is, you do not come back to the original point; if you do it in a perfect lattice, this circuit will flows So this circuit does not close, so that means this is the vector by which circuit is not closing and this vector is called burgers vector, and also we will know that (( )) relationship burgers vector is also exactly same as the slip vector.

Now, this slip vector is pointing this direction, so one one does stress calculation it is quite important to define the burgers vector, because the stress field or the energy (( )) stored energy of a dislocation will be a strong function of this vector, and in this particular case when this act this extra (( )) of atom lies above this slip plane. This is the slip plane, this is the extra plane of the atom above this slip plane.

And now this type of arrangement here this burgers vectors is pointing in this direction, (( )) let us say the positive direction of say an x axis, so this is called a positive edge dislocation. The burgers vector is positive, so burgers this types of dislocation edge dislocation (( )) in the in the crystal you have a extra half plane. And this extra half plane lies an upper half of the slip plane. Now, look at nature of the stress field it looks that upper half is compressed, here you have an a extra plane which is compressed together, so you upper plane half is compressed, and lower half you know the distances are little more here. So, here lower half you can visualize as if the lower half is under tensile stress.

So, if you try to move this dislocation you can what you will do, if you do a work if you do a positive work this displacement is like this, so you do a positive work and an the bottom side this it is opposite to the vertex vector. So, burgers vectors that is placement vector, so here the work done is negative, so in a way to move this dislocation from this (( )) to the other side you know you do not spend much energy. So, that is why you by assuming the crystal, that crystal contains dislocation defect called line defect called dislocation, it is possible to a x plane, why the shear stress required to called slip is so low. So, in reality this stress will not be zero, you have to move this location; that means it has a surrounding stress field and this stress field will interact with the periodic stress field which is exiting within the crystal, so to move this stress field within a periodic stress field you will need a small amount of lattice friction stress, which is to be overcome. So, you need on this stress is much smaller than the ideal strength of the crystal.

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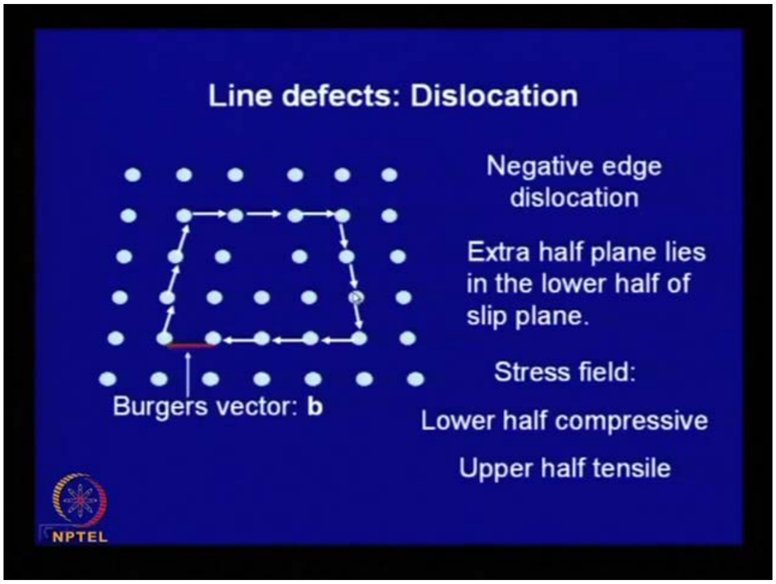

Line defects: Dislocation

Negative edge dislocation

Extra half plane lies in the lower half of slip plane.

Stress field:

Lower half compressive

Upper half tensile

Now, look at the case of a negative edge dislocation which is shown over here, so here the extra half plane is below the slip plane. And here if you try and describe in burger circuit you will find that this vector slip vector or vector needed to complete the circuit, it points in the direction against x axis, this is the x axis the opposite to the x axis. So, therefore we call this vector, this is the negative burgers vector, and we call this dislocation and negative edge dislocation.

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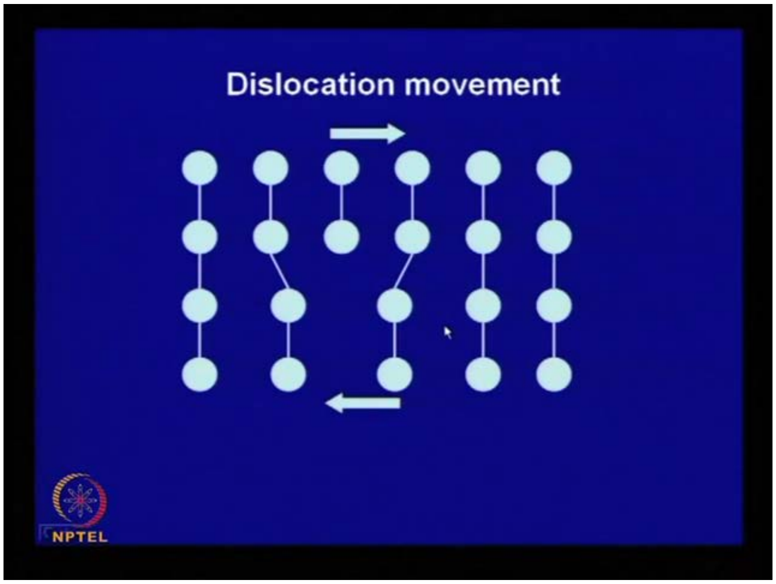

Dislocation movement

And look at how does this dislocation moves, to move this dislocation you have to apply shear stress, which is shown over here. So, this is the extra half plane, so this is a crystal not a perfect crystal, the lattices are strain and here you try and push apply a shear stress and when this shear stress overcome this lattice frictional stress which (( )) dislocation motion, then what happens? It moves to the next point you apply a till continue comes here.

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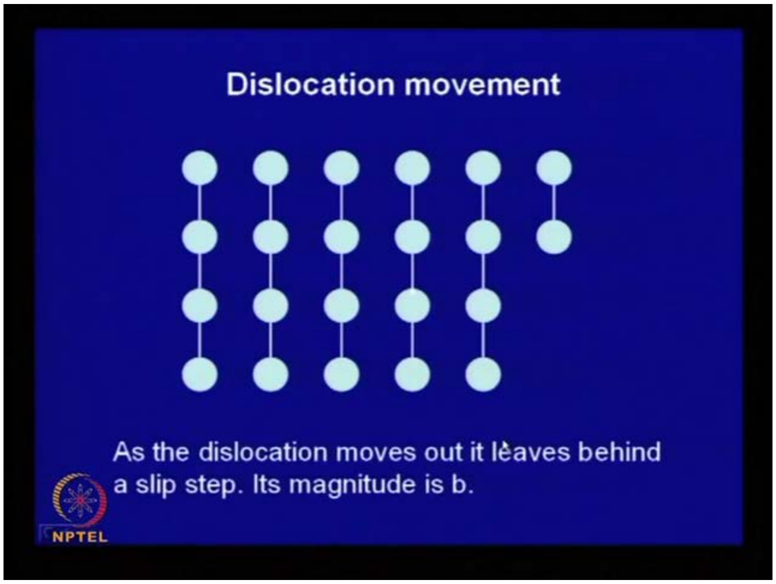

Dislocation movement

As the dislocation moves out it leaves behind a slip step. Its magnitude is b.

And finally you are left with a slip step. So, dislocation moves out of the crystal leaving behind a slip step, and the magnitude of the slip step is same as that of the burgers vector.

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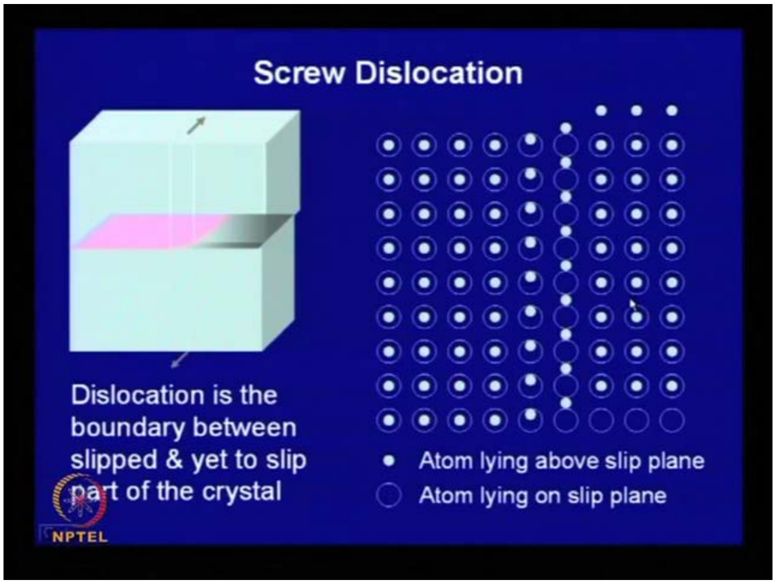

Screw Dislocation

Dislocation is the boundary between slipped & yet to slip part of the crystal

- ● Atom lying above slip plane
- ○ Atom lying on slip plane

Now, then is another way you can create a dislocation which is called screw dislocation, which is shown here and this diagram and a (( )) little time to visualize what this diagram shows? So, this is a crystal imagine; and imagine a plane here. Say we let us say that this plane we have sliced, and we are applying see a stress in this direction and this direction, so on the top and bottom we are applying the shear stress on the top and bottom and opposite direction, and this is the deformation (( )) like this; this is the boundary. And so therefore this part of the crystal has the crystal has slipped. Move one atomic distance forward. Only this part has moved one atomic distance forward that means slip towards this particular plane, whereas this part is yet to slip. So you, so basically this is the dislocation line, your shear stress is applied along that direction and this dislocation moves perpendicular to this direction. This is the dislocation line and dislocation moves here perpendicular to the direction of the line, but Burgers vector, the slip vector is along this direction. So that means Burgers vector here is parallel to the dislocation line. So the lattice around this point, around this line will be distorted and which is diagrammatically shown here.

If you look carefully, there are two layers of atoms have been plotted. One represented with the this dotted line, this is the dotted line that larger circle; this represents atom lying on the slip plane; and this solid points, this represents atom lying above the slip plane. And what happens, you apply the shear stress, when you apply the shear stress, the top part top plane has slipped one atomic distance this side. So these three they have moved here, but this part is here to move and in between there is a region, where atomic arrangement is little disturbed. So here these atoms have moved a fraction of this atomic distance is something like this. So basically, if you look at three d picture, so basically this atom you know if you can visualize this, this atom will be adding (( )) along the line of a screw; imagine a right handed screw like this and this atoms are displaced around that in a helical way. Around that they will be disturbed like that. Obviously this will be associated with a stress field.

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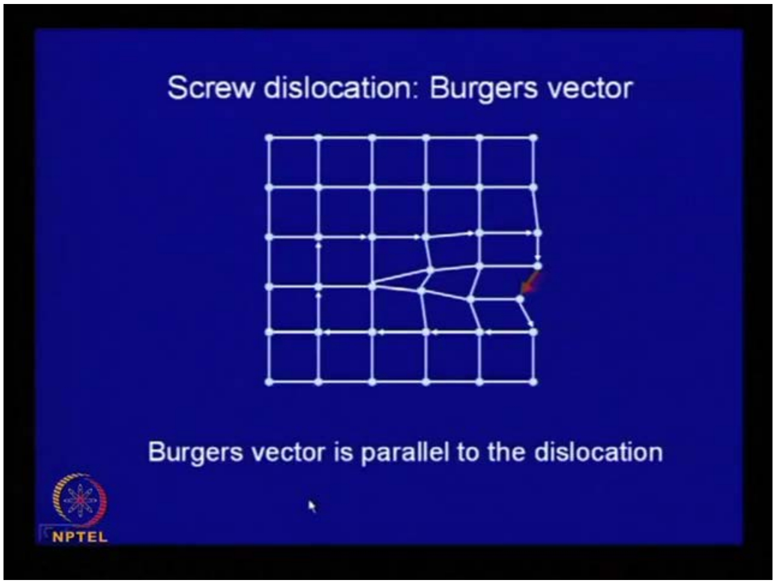

Screw dislocation: Burgers vector

Burgers vector is parallel to the dislocation

And here look at that atomic arrangement here, I mean I have tried to draw that and here also to determine the Burgers vector. You have to construct a Burgers circuit, which is shown over here. So this part (( )) arrangement is perfect possibly here; this is perfect. Around this, there is a distortion here; and this is the slip step which has formed. And here, if you try and scribe a clockwise Burgers circuit, you will find that you move you know that two distance here, here also you moved this direction, here four atomic distance, here four atomic distance that balances. But here, the vertical direction to atomic distance at here is one and here there is a one atomic distance. So when you can construct that full 360 degree cycle, you will find there is a slip step. I mean a vector, I mean which does not complete this circuit and you need an additional vector to complete this circuit. And this is in the direction perpendicular to this plane of the drawing. So basically, if if we consider this is x axis, this is y axis, if we consider this is z axis, so this is along the direction positive direction of the z axis. And this type of dislocation is called positive edge dislocation.

In the same way, you can have a negative edge dislocation where you know either you invert it like this. You assume that this top part comes forward; here this top part has gone behind the plane, this top part has gone behind the plane of this drawing. Whereas, if you imagine, this top part comes out of the plane towards you and that case, this slip vector will point in this direction, that is opposite to against the z-direction. That’s what the, in that case that type of the dislocation we will call a negative a screw dislocation.

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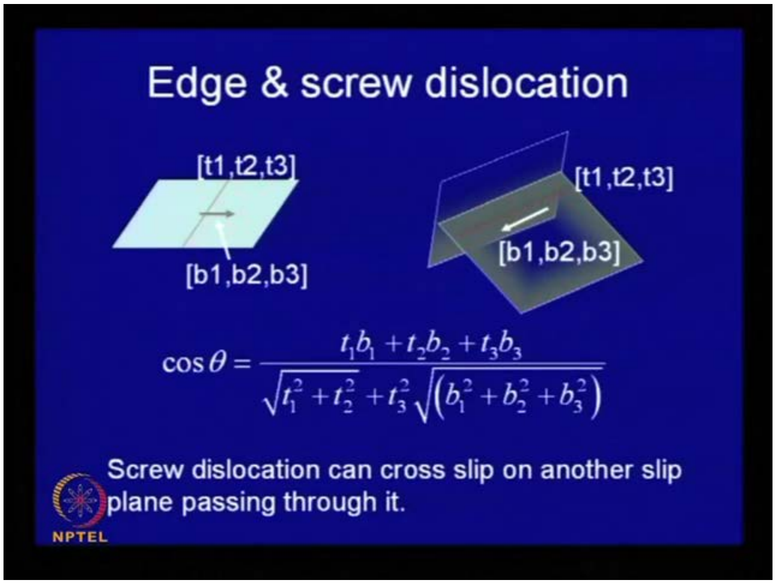

Edge & screw dislocation

$$\cos\theta = \frac{t_1b_1 + t_2b_2 + t_3b_3}{\sqrt{t_1^2 + t_2^2 + t_3^2}\sqrt{(b_1^2 + b_2^2 + b_3^2)}}$$

Screw dislocation can cross slip on another slip plane passing through it.

Now it will be interesting to know let us compare the two – the edge and screw dislocations. Edge and screw dislocations, if you look carefully, two things are happening. See, one imagine a screw dislocations. Say this is a line, which separate this part has slipped. This is a to slipped, this is the Burger vector, and dislocation line will always move perpendicular, any dislocation will move perpendicular to movement direction to that its location like this. And this is the slip vector, in that case, you have this is the dislocation line, this is the slip vector and angle between this and this is 90. And which you can easily say in a crystal, we will see some example. In a crystal, see in suppose if this is a slip plane, you know the miller indices of the slip plane. So slip plane will contain for the dislocation to move for this to be a slip plane for this dislocation. The

Burger vector and the dislocation direction both must lies on the slip plane then only the edge dislocation can utilize.

Now situation in the case of screw dislocation is little different. Now this is the screw dislocation. Let us say this line is the screw dislocation and this is lying on this plane, but through the (( )) its burger vector is parallel to the dislocation line. So therefore, the mobility of this is much more, it can glide, it can glide on this plane on which it is lying or it can on any plane, any slip plane which is passing through this line. Say suppose when this dislocation moves up to here, so this is the plane which is intersecting along a line parallel to the dislocation line. So it can move along this plane also, which is not possible in case of edge dislocation. Edge dislocation will always have a definite slip plane whereas screw dislocation can move on to another slip plane. It can cross slip say from here it is moving along it slip it can cross slip into this plane. And so therefore, it is very easy say suppose will check say if this dislocation burger vector is given, the slip plane is given and it is quite easy to know, so which dislocation will be mobile which will not be mobile.

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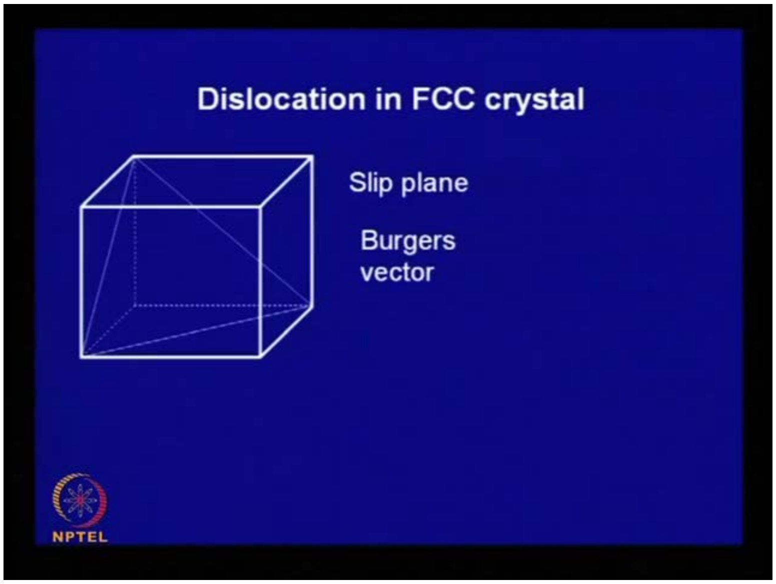

Dislocation in FCC crystal

Slip plane

Burgers vector

So let us look at this little more carefully with respect to let us say face centered cubic structure.

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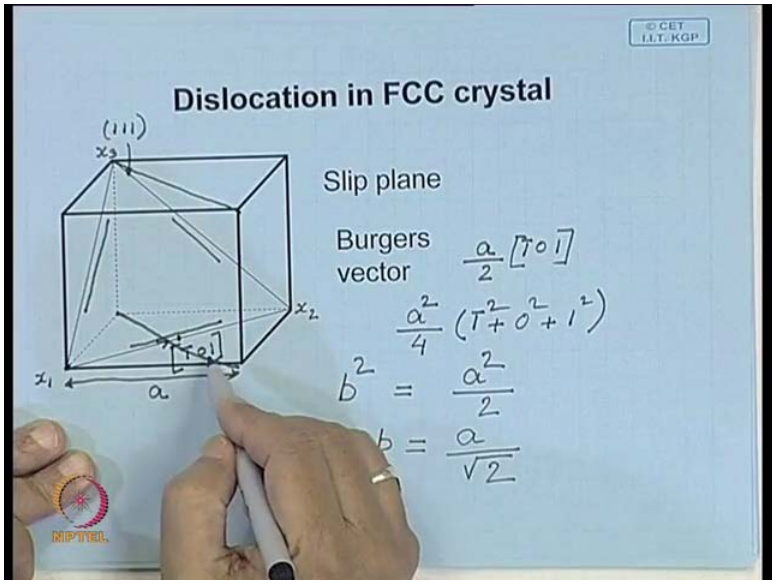

Dislocation in FCC crystal

Slip plane

Burgers vector $\frac{a}{2}[\bar{1}0 1]$

$\frac{a^2}{4}(\bar{1}^2+0^2+1^2)$

$b^2 = \frac{a^2}{2}$

$b = \frac{a}{\sqrt{2}}$

So face centered cubic structure, so basically face centered cubic structure the slip plane, the face centered cubic structure slip plane is the plane 1, 1, 1. Plane 1, 1, 1 is the slip plane and we also learn that slip direction is the closed packed direction, that is 1, 1, 0 type of direction, that is face diagonal. Now look at one, one, one plane, it has three face diagonal. Now what is the indices of this particular direction. This plane is one, one, so if we assume this axis is a;

this is b, this is c the crystallographic axis or we write it x 1, x 2, x 3. In that case, this direction this is one bar, it goes here, from here to here you have to go. You move one step against x 1, so one bar then one along this, so this is the direction. And what is the Burger vector? Burger vector is one atomic distance along this. So this distance is from here to here, so half of this. So usually, so therefore if we say that lattice parameter, if it is a we will say this Burger vector you can write it as a over two, one bar zero one. So this is the vector representation. If you want to find out the magnitude of the Burger vectors is quite easy, the magnitude will be what you do is do four, this is one square square. So therefore, this becomes equal to a square over two. So this is b square; so b is therefore b is a over root two.

Now check this, say suppose what is the Burger vectors says, suppose if this we say that this is… This Burger vector can you draw a screw dislocation on this, which is very easy. A screw dislocation is line along the direction. So a screw dislocation, any direction so this if a dislocation on this plane lies along this, this is a screw dislocation. If I dislocation lies like this, it is a screw dislocation. If it is lies like this, it is a screw dislocation. But if it has to be an edge dislocation in that case, you know this is the direction it must lies in a direction which is on this, but it must be something like this. So you visualize this plane. So this plane will intersect you you intersect this plane along a particular directions which is which will be and this is the direction which lies on this plane but perpendicular to this, which is quite easy to check.

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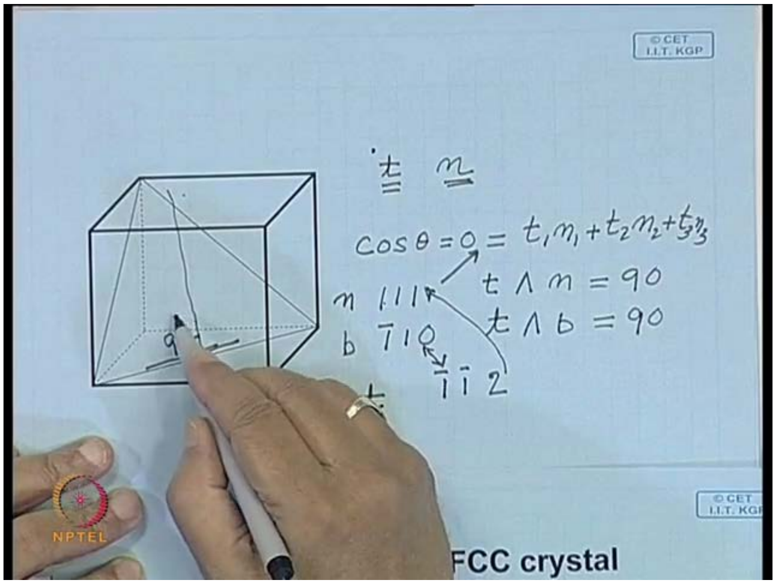

If you recollect that cos theta the one direction say a direction a direction say t whether it lies in a plane n. It is the vector representation at direction t, a vector t lies on plane n. So, this plane vector, so first need to check whether they are at right angle. So you check cos theta angle between this and the plane normal should be 90, so that means this is zero. So that is t 1 n 1, t 2 n 2, t 3 n 3, this should be zero. So suppose this plane is one, one, one; so this direction it should lie on this. So this direction this t should be perpendicular angle between t and n; this is 90. Say angle between t and the Burger vector this also should be 90. For then only this will be an edge dislocation.

So you try and find out, so therefore it is there are not many option. So basically, one option is say this is Burger vectors, this is the plane n the Burger vector is one bar one zero. So, you can think of a line say another plane, say which is perpendicular to this as well as here. So I try this as an exercise, a direction say t find out the t which is perpendicular to this as well as this. So one I can say suppose this is check this. You can do it easily by forming to equation. Another if you can look at this standard projection or if you can visualize, so this is the direction let us say one, look at this direction one bar one bar two. Now if you direction is one bar one bar two, in that case here it satisfies this condition. You substitute it here, here it's satisfies this condition. Now does it satisfies the same condition here, you check. So that means only if that dislocation lies along one bar one bar two. So one bar one bar two, so basically so one bar one bar two may be some direction is something like this which is on this plane. In that case, which is lying on this on its obtain 90 degrees. So that means, a dislocation edge dislocation to sum up what we can say that we learned about two types of line defect edge and screw, out of this two dislocation is much more mobile, it can move on several slip system. But for edge dislocation movement is restricted. And next class, we will (( )) upon this and we will see how the concept of dislocation help us to understand the deformation behavior of metals. Thank you.