Creep Deformation of Materials
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Part 3
Basics of plastic deformation and characteristics of dislocations

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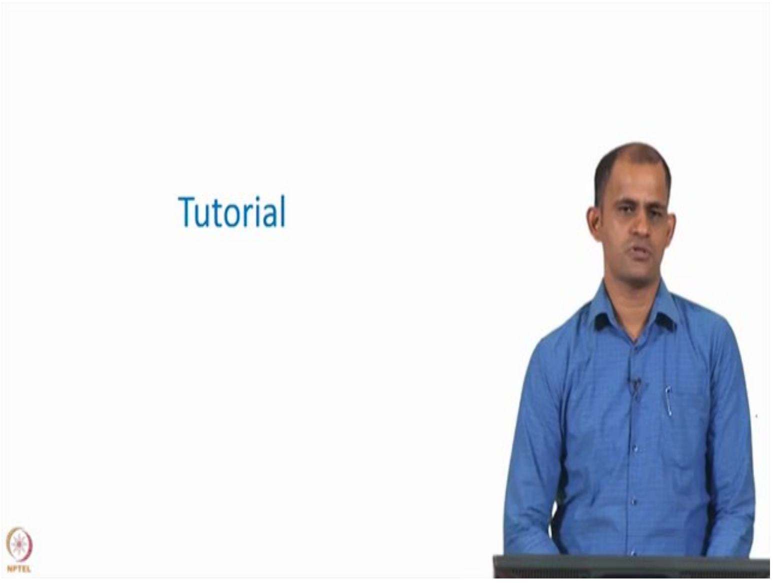

Alright, so this will be the tutorial for the lecture which covered the applications of so this is basically a tutorial where we are going to talk about some of the concepts so problems associated with some of the concepts that we are discussed in the previous set of slides. So in the previous set of slides we talked about the concept of creep and it is important in different industries and we talked about the role of stress and temperature, we talked about characteristic of dislocation and how dislocations move when the face an obstacle and things like that.

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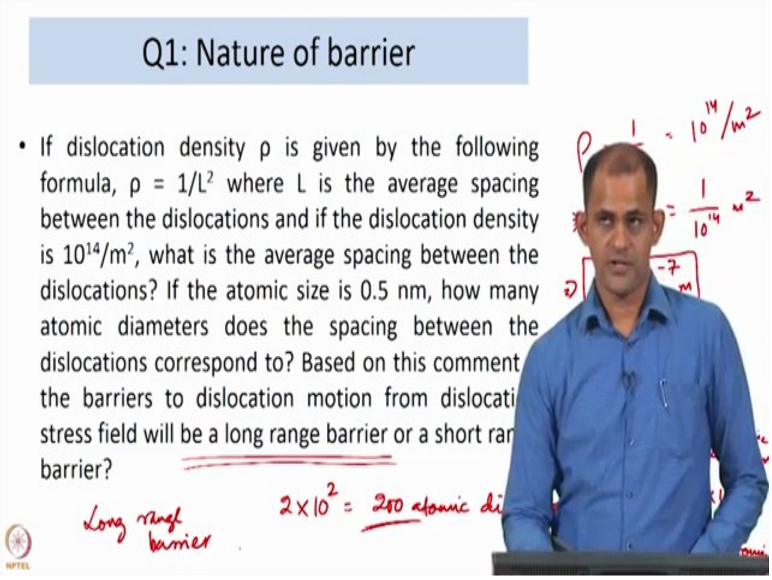

So this tutorial is going to introduce you to some problems associated with the concepts discussed earlier. So the first question is about nature of a barrier, so let us go through this question, so if the dislocation density rho is given by the following formula so rho is generally related to the inverse of the square of average spacing between dislocation, so rho is equal to 1 over L square where L is the average spacing between dislocations and if the dislocation density is approximately ten to the power 14 per meter square what is the average spacing between the dislocations, so that is the first part of the question,

Now if the atomic size is point 5 nanometer so if the atom diameter is say point 5 nanometer how many atomic diameters does the spacing between the dislocations correspond to and so based on this comment if the barriers to dislocation motion from dislocation stress field will be a long rage barrier or a short range barrier. So this question is about long range barrier or short range barrier if you recall long range barriers are those which cannot be overcome by thermal fluctuation where a short range barriers are those which can be overcome by thermal fluctuation.

We also talked about long range barriers being of the order of a hundreds of atomic diameters, so because the distance over a which the dislocation will have to overcome is a few hundred diameters that is why it is long range and short range is may be a couple of a few atomic diameters say ranging between a 1, 2 may be 5 or so and because they are so small in number because the distance is so small in number it can be easily overcome by temperature.

Now let us determine if this dislocation spacing will lead to a long range barrier or short range barrier, so since rho is 1 over L square this implies L square is equal to 1 over rho so that is 1 over 10 to the power 14 meter square this implies L is 10 to the power seven meter. Now this is the average spacing between the dislocations corresponding to that atomic that dislocations density.

Now atomic size is point 5 nanometer so how many atomic diameters does the spacing between dislocations correspond to? So first let us convert this into nanometers so this is 10 to the power minus 7 into 10 the power 9 that is equal to 10 to the power 2 nanometers, so the average spacing between the dislocations is around 10 to the power 2 nanometers. So point 5 nanometer corresponds to one atomic diameter so 10 to the power 2 nanometers will correspond to 1 by point 5 in 10 the power 2 that is equal to 2 into 10 to the power 2 atomic diameters.

So the average spacing between the dislocations approximately corresponds to (2 to the power) 2 into 10 to the power 2 which is 200 atomic diameters. So this is the effect so the long range stress field or the stress field because of the dislocations spacing is working over a distance of around 200 (nano) atomic diameters which means for the dislocation to overcome it has to at least travel 200 atomic diameters since this is significantly larger than what we generally know for a short range barrier, so this the internal stress field because of the dislocation is corresponds to a long range barrier, so the answer to the question is that this is a long range barrier. So that was a first question.

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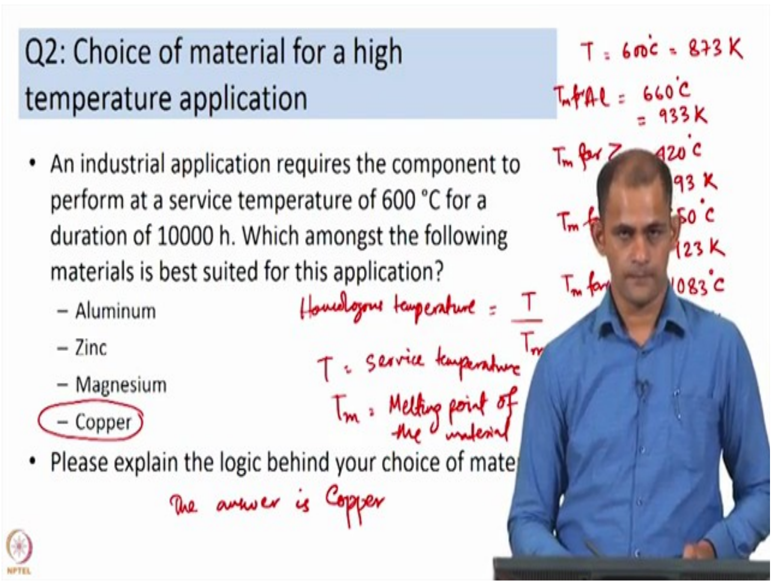

Now let us look at the second question. So the second question is how do you choose a material for a particular high temperature application? So if you know the service conditions, if you know the stress and the temperature at which the material is going to work then you will be able to make an educated gas or choice for the material that you need to use for that particular application.

So this question is based on that so an industrial application requires the component to perform at a service temperature of 600 degree centigrade for a with a service life of 10000 hours. So if you are given 4 different materials so the 4 different materials are listed here aluminum, zinc, Magnesium and copper which of these materials do you think will be best suited for this application.

So the material has to survive a service temperature of 600 degree centigrade for at least 10000 hours, so which material of those listed below would you choose for this application and why? So the answer is copper, so the correct answer is copper and now I will tell you the logic behind the answer, so if you recall a first thing that I said for creep is homologous the concept of homologous temperature I had introduced you to the concept of homologous temperature in the first few slides on creep. So the zinc for a given temperature you have to determine the homologous temperature of the material and if the homologous temperature is very high then that material will not be suitable for the temperature at which your material is going to work.

Now let us compare the homologous temperature of these 4 materials so homologous temperature is given by T over T m, T is the service temperature and T m is the melting point of the material. Now let us look at we know the service temperature T is equal to 600 degree centigrade so we have to convert it into kelvins so this becomes 873 kelvin. Now the melting point of aluminum is T m for aluminum is 660 degree centigrade which means it is 933 kelvin, T m for zinc is 420 degree centigrade which is 693 kelvin, the melting point for magnesium is 650 degree centigrade which is 923 kelvin and the melting point for copper is 1083 degree centigrade which is 1356 kelvin.

So if you now calculate for each of the metals the homologous temperature will find for aluminum the homologous temperature is point 93, for zinc it is 1 point 25, for magnesium it is point 94 and for copper it is point 64. So zinc clearly the service temperature is higher than it is melting point which means zinc is going to melt at that service temperature and can automatically can be ruled out for that application and for aluminum, magnesium also the T by T m is very high so among all these materials the material which has the lowest T by T m or the lowest homologous temperature is copper which means the material will have high creep resistance at that temperature and within the listed (alu) metals copper could be chosen for this application.

Of course while choosing the material other aspects of the application including cost. As industries are sensitive to cost so when you choose a material or propose a material for a particular application you will also have to account for the cost of making a part with that material but if you ignore those things including other environmental aspects such as perhaps the material needs to be also corrosion resistant or fatigue resistant etcetera if you ignore all that and base our choice only on creep resistance than for this particular problem copper is the answer because it has the lowest homologous temperature among the lot. So that is the logic behind the choice of copper.

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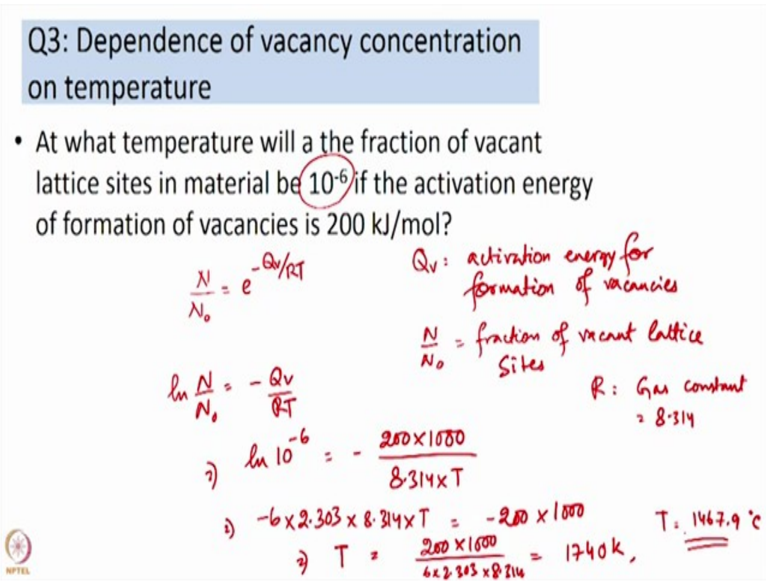

Now let us look at the third problem so this is this problem relates to understanding vacancy concentration as a function of temperature. So if the activation energy for formation of vacancy for a material is 200 kilojoule per mol and if you want that the fraction of vacant lattice sites in the material be 10 to the power minus 6 than at what temperature should you equilibrate the material to achieve this fraction of vacancies.

So that is what the question is about and to solve this question we are going to use this relation, so N over N not is approximately equal to e to the power minus Q v over R T so Q v is the activation energy for formation of vacancies. So if you recall this for something we talked about on the slide on point effects especially with relation to understanding the interaction between dislocations and point effects, so this relation is coming from there so Q v is the activation energy for formation of vacancies and N over N_0 is basically the fraction of vacant lattice sites.

So the problem than basically converts into following so you have to determine take log on both sides so that becomes so this implies log of 10 to the power minus 6 is equal to 200 into 1000 divided by 8 point 314 into T, so R is the Gas constant which has a value of 8.314 so if you used that, so minus 6 into so this implies temperature T will be 200 into 1000 divided by 6 x 2.303 x 8.314 so that will turn out to be 1740 kelvin and so the temperature in degree centigrade will be 1467 point 9 degree centigrade.

So if you hold your material at that temperature for a significantly good period of time than you will be able to achieve vacancy concentration of 10 to the power minus 6 in your material.

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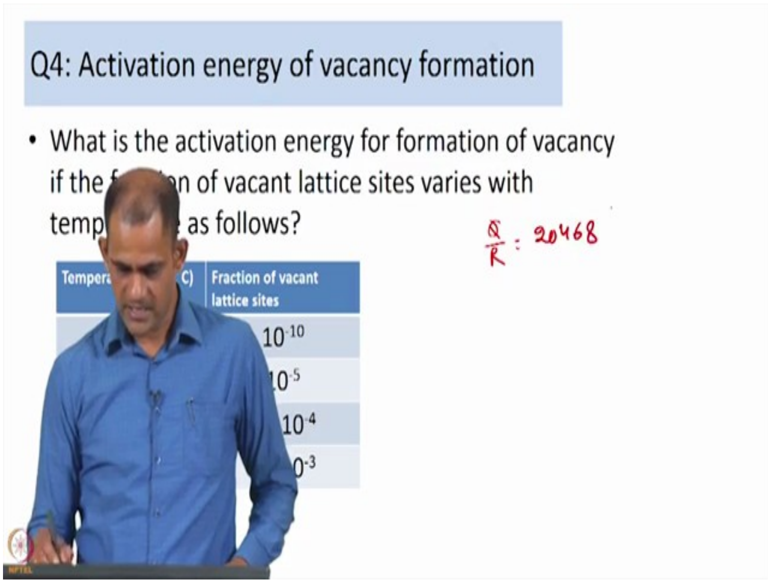

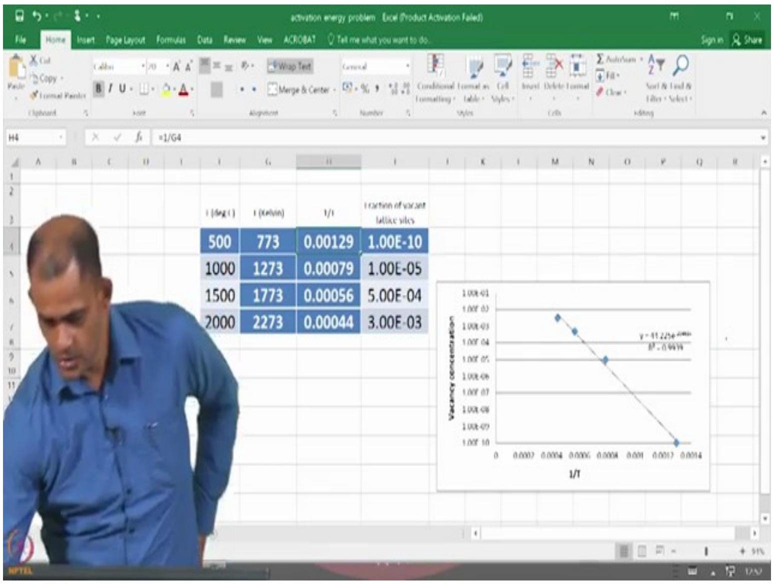

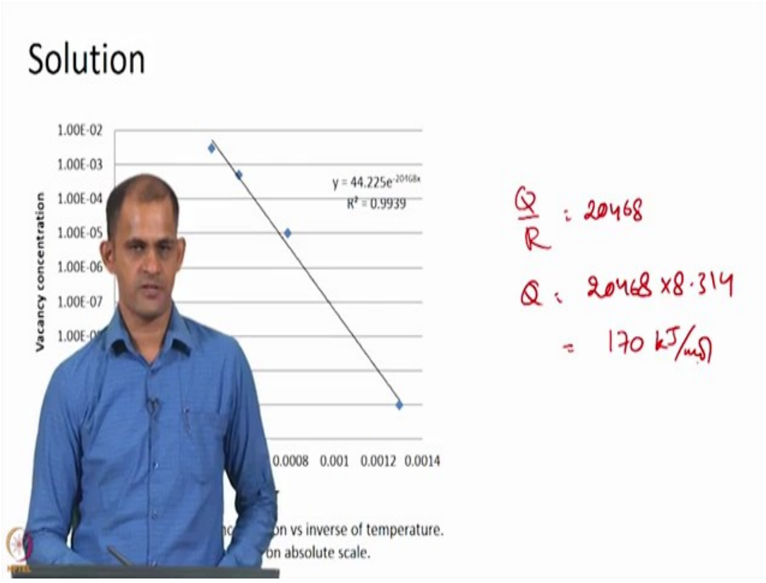

Now let us look at a slightly different version of the same problem. So in this problem we are talking about this problem is a slightly different it is a variation of the earlier problem in the sense that I am asking you to determine the activation energy for formation of vacancies and what have given you is different temperatures and the fraction of vacant lattice sites corresponding to these different temperatures.

So again we are going to use the same relation N over N_0 is e to the minus Q v over R T and what we are interested in knowing is Q v so let us go to the this excel sheet so what you need to essentially do is take the temperature in kelvin take the inverse of it and plot the inverse of temperature against the fraction of vacant lattice sites this is called an arrhenius type of plot so when you do that you will see the data would more or less when you plot the natural logarithm of the (vacant) vacancies concentration vs. the inverse temperature you will get a linear plot and the fit of for this data is given by the following equation here so you have the y axis as a function of x and with a constant involved.

So if you look at the exponential term you have minus 20468 into x and x we know is over T and so the other term is (what) equal to Q over R so 20468 is actually Q over R so if you now go back if you now comeback to this slide, so what we got from that linear fit is the value of Q over R is equal to 20468 so Q over R is equal to 20468 so Q will be 20468 into 8.314, so that turns out to be 170 kilojoule per mol.

So this is the activation energy for formation of vacancies in that material and with this you can than determine the vacancy concentration at any other temperature of interest. So that was the approach, basically this problem tells you the approach to be used for determining the activation energy of vacancy formation in a material and similar concepts will also be used in understanding creep and activation energy for creep.

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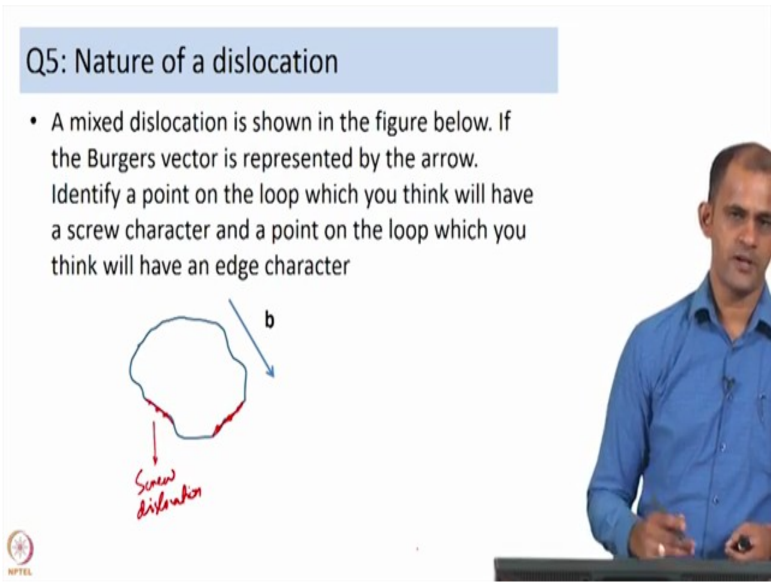

To the next problem since we have talking about dislocations, so the next problem is about understanding the nature of the dislocation. So here a mixed dislocation is shown in the figure and if the burgers vector is represented by the arrow what I want you to tell so this is a dislocation loop it has a mixed character and so what I want you to tell me is (what) identify at least a point on the loop which you think will have a screw character and a point on the loop which you think will have an edge character.

So that is what the problem is and for this you need to go back to the portion where I introduced you to dislocations and I was talking about screw dislocations and edge dislocations and if you know the characteristic of an edge dislocation and edge dislocation is a dislocation where the burgers vectors is perpendicular to the dislocation line and screw dislocation is one where the burgers vectors is parallel to the dislocation line.

So now let us look at this loop and find out which point at least there are several points but let us look at a couple of a points so which point do you think will approximately correspond which will be approximately parallel to the burgers vector. So this segment of this dislocation will be more or less parallel to the burgers vector which means any point on this segment can be called a screw dislocation. Any point on that segment will have a screw character.

Now let us look at a portion of the dislocation which is almost perpendicular to the burgers vectors, so if you look at this segment of the dislocation loop it is almost perpendicular to the burgers vectors, so it means this portion of this dislocation the segment of would have an edge character and so any point on the segment will also have an edge character. So that is how you can determine the nature of a dislocation or the nature of a segment of a dislocation loop.

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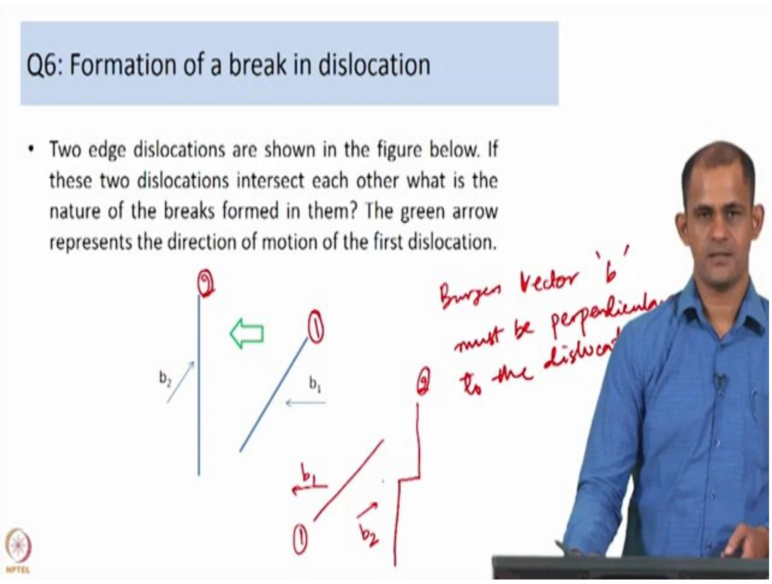

So now continuing in this with concepts on dislocation (let us look at) let us visit the concept where we talked about the formation of breaks in dislocations. So if you recall jogs and kinks so we talked about the formation of jogs and kinks when dislocations intersect with each other of course there are certain rules for the formation of a jog and for the formation of a break in a dislocation.

So we will discuss we will get an understanding of that by solving this problem, so here I am showing you two edge dislocations these are edge dislocations because the burgers vectors is perpendicular to the dislocation line. So you have dislocation line 1 and you have dislocation line 2 and they are going to intersect each other, so the question is what is the nature of the breaks that forms in these dislocations, so when these dislocation intersect with each other so the arrow signifies the direction in which the dislocation 2 is moving towards dislocation 1.

So what is interesting is both these dislocations will not develop breaks only one dislocation will develop a break and the dislocation that will develop a break is dislocation 1 that is because for a break to form it is important that the burgers vectors b must be perpendicular to the dislocation. So if you look at these two dislocations the burgers so I am calling this 2 so let me call this as dislocation 2 and this is dislocation 1, so yeah so we are looking at two dislocations, dislocation 1 and dislocation 2 and the question is about finding out which of these two dislocations whether these dislocations will develop a break when the intersection when they intersect each other or interact each other.

So for that the important point is the burgers vectors of the intersecting dislocation must be perpendicular to each other but if you look at the two dislocations here what we see or what we notice the burgers vectors of dislocation 2 that is b 2 is parallel to that of dislocation 1 so the burgers vectors of dislocation 2 is actually parallel to dislocation line 1 which means 2 will not create any break in 1 where as dislocation line 1 the burgers vectors b 1 is perpendicular to dislocation line 2 which means dislocation line 2 will develop a break at the end of the intersection.

So this is what will happen after the intersection, so this is how 2 will look like whereas 1 will continue in the way it was going, so b 2 and so this will be the break that will form in dislocation line 2. So this was about this problem was about formation of a break in a dislocation.

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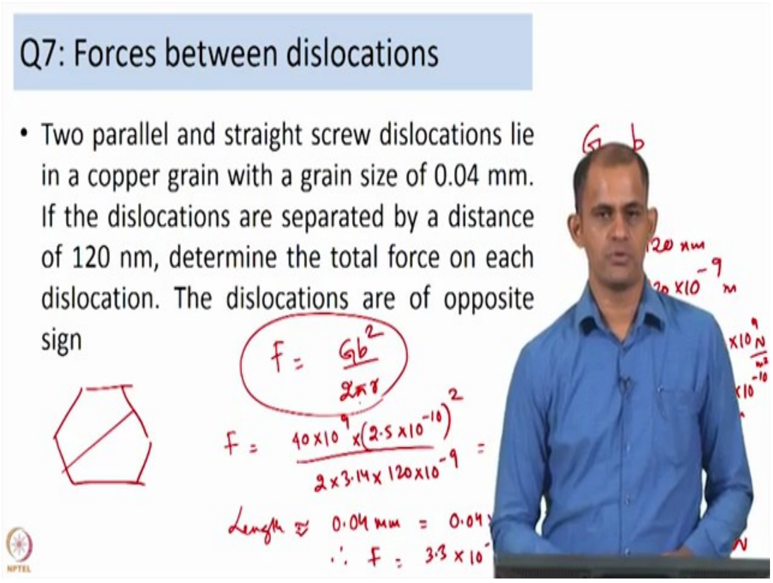

So the next question is about forces between dislocations so because of the stress field that is present around the dislocation, dislocations those stress fields will ensure interaction between dislocations so this is 1 question about how the kind of forces that might exists between dislocations. So you have two parallel and straight screw dislocations present inside a copper grain with a grain size of point 04 millimeter and now if the dislocations are separated by distance of 120 nanometers determine the total force on the each dislocations, if the dislocations are of opposite sign.

So the question is to determine the force acting between the dislocations. So the force is given by G b square by 2 pi r so for copper we need to know G, we need to know the burgers vectors b what is given is the distance between the dislocations which is 120 nanometers so that is 120 into 10 to the power minus 9 meter. So for copper the shear modulus G is 40 gigapascal and the burgers vectors is 2 point 5 angstrom, so the burgers vectors comes about from the crystal structure copper has an f c c crystal structure and you can find out the burgers vector from the lattice parameter of copper and so it is 2 point 5 angstrom which is equivalent to 2 point 5 into 10 to the power minus 10 meter.

So with these information now we can determine the force, so the force is force per unit length so this is equal to 40 into 10 to the power 9 into 2 point 5 into 10 to the power minus 10 square divided by 2 into 3 point 14 into the distance, so if you calculate these you will see that the unit is the force per unit length is 3 point 3 into 10 to the power minus 3 newton per meter, so once you do the calculation that is what that is the answer that you will get.

Now this is force per unit length so if that is what you have the unit is as newton per meter but if you want to find the absolute force acting on the dislocation than will have to make a small assumption so will have to assume the length of the dislocation so since the grain size of the material is around point 04 millimeter so we can assume perhaps that the length of the dislocation can be approximately taken as point 04 millimeter so that is point 04 into 10 to the power minus 3 meter, so therefore the force total force acting on the dislocation is 3 point 3 into 10 to the power minus 3 into point 04 into 10 to the power minus 3, so that will come out as 1 point 3 into 10 to the power minus 7 newton.

So that is a total force acting on each dislocation because of the present of a neighbouring dislocation. So this is how so this is this problem involves you to use this relation Gb square by 2 pi r to understand the force per unit length existing between two dislocations. So with that I come to the end of the tutorial and we will at a later stage will do some assignments based on some of the concepts introduced in this first set of lectures, so thank you.