Electroceramics
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Lecture - 16

So welcome to this new module which is on dielectric properties. So, what we have done in past is to look at the in module we looked at the structure of ceramics. So, we looked at various kinds of structures starting with f c c packed structures, where typically anions make a f c c lattice and cations fill the interstitials site whether it is octahedral or tetrahedral. Now, since the structure remains f c c which means cations of lattice is also f c c.

So you could represent the structure by either taking cation as the corner of the lattice or anion is the corner of lattice, it does not matter, but given that anions are bigger in size. The usual convention is to put the lattice on the anions sides, convention lattice. And then second form we discussed was slight deviations from f c c packed structures, for example prostate structures, where the structure appears as if it is a f c c lattice, but it is not. It is a, it is a basically a primitive cubic lattice.

So examples are a b o thick kind of structures such as barium titanate, lead titanate etcetera. And these are very important materials technologically they are ferroelectric and piezoelectric materials. And then we looked at cesium chloride kind of structures, (( )) structures, and then we moved on to taller structures which are y b c o kind of structures, which again contain perovskite units in them, but they are, they could be orthorhombic or tetragonal depending upon the material. And then we looked at h c b packing of structures such as wood site or your lithium niobate, etcetera.

Finally, so this was the module which, in which we covered structure of ceramics. Then we moved on to, what we called as defect chemistry and defect equilibrium. This was a very important module from the point of view of properties, because defects play a very important role in tailoring their properties of ceramic materials, especially electro ceramics. Electrical properties such as conductivity, they are dependent upon defect concentration, because they do not have free charges as such as a presence of mobile defects such as oxion vacancies which make them conducting. That is why you have oxides like zirconium oxide, which when doped with certain amount, certain type of, and certain amount of material become extremely conducting. And then you have some fast ion conductors which are intrinsically fast, because of presence of mobile ions.

So all this was a, all this was done in order to develop an understanding of defect equilibria in the ceramic systems, typically oxide systems and electrical properties. And now, and we also looked at some applications like fuel cells etcetera. So, if you want to go into details, I have suggested couple of a few reference books which are also given in the beginning of the course, as well as I have suggested from time to time. Now this, now we move on to, so we have covered conduction in ceramic materials, now we move on to completely different part of spectrum.

As we know that most of the ceramics are insulators. That is a truth. And this insulating property of the ceramic is very useful. This makes them electrically insulating material, which we also often refer as dielectrics. Dielectrics are technologically very useful. They are used in many electrical applications. For example, the poles that you, the electrical poles that we see on the roads they contain these big ceramic parts. They are nothing but your insulators. They are, they can also be used as capacitors, they can be also be used as your sensors, actuators etcetera, depending upon the type of ceramic. So what we will do is that, we will, we will first look at simple dielectric ceramics which are linear in nature.

First we will go through the basic principles of these dielectric materials. Then we will look at some more complicated things. And once we cover this simple dielectric part, we will move on to complicated or non-linear dielectric kind of special dielectrics. As we can, if you can allow me to say. So dielectrics are basically insulating or non conducting material, and they are used in variety of applications such as sensors or actuators or capacitors or memories etcetera. I mean, there is, there is no limit to applications of these dielectric materials technologically.

For the sake of simplicity, we can assume that in these materials there is no long range conduction of charges unlike the previous counterpart that we saw in module three where we as, where we were interested in long range conduction of charges. So, here we assume that there is no long range conduction of charges, which means, charges move only to very short distances. When there is long range conduction then there is another problem that we will discuss later on. So, what we will do is that first we will look at the behavior of dielectrics in D C field.

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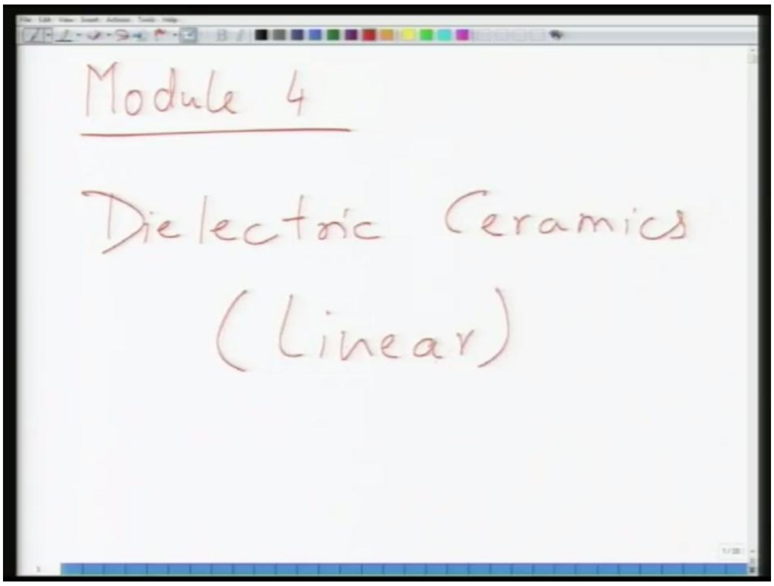

So, I will start this module as, so this is dielectric ceramics. So, we will say basically these are linear dielectrics.

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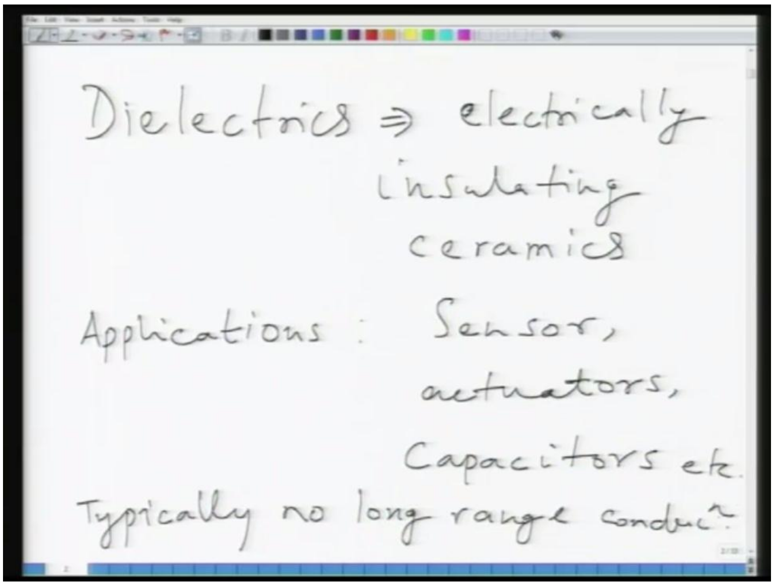

And, so what we will do is that, first we will look at; or maybe I will first, so dielectrics are electrically insulating ceramics, and they are used in variety of applications as I said; sensors, actuators, capacitors, etcetera, plenty of applications depending upon the type of the ceramic and typically no long range conduction.

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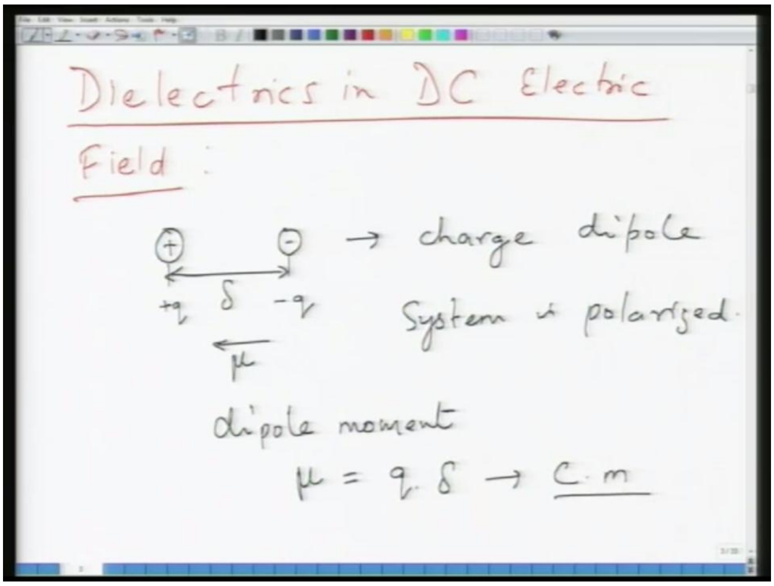

So, what we will first do is that, we will first look at the behaviors of these dielectrics in D C field, so dielectrics in D C electric field. So, now upon in a normal material when you apply a D C field to a material, there is a long range movement of charges, migration of charges. However, in these materials, there is limited movement of charges or short range only, and this leads to separation of, let us say, a bunch of positive charges with respect to bunch of negative charge. Or, within an atom itself, there is separation between centre of positive charge and centre of negative charge. This leads to creation of what is called as a charge dipole.

So when you apply electric field, so what happens? If you have a positive charge, and a negative charge, they have separation between them. This is plus q, this is minus q, and this distance, which is a between these two charges, is let us say distance delta. And if this happens, then what this is called as a charge dipole. And this system is called as upon application of field as polarized. So, and the dipole movement is taken from.

So system is polarized. Now, when we say that this system is polarized, which means the system generates some sort of dipole moment, and as a result of creation of this dipole moment, what you induce is, what is called as polarization. So an electric dipole basically electrical or charged dipole basically comprises of two equal and opposite charges, which are separated by a distance delta, and the resulting dipole moment, which is defined as mu. So, dipole moment mu is given as q dot delta, dot product of the magnitude of charge with the distance.

Typically, it is a vector but in most of the circumstances we take it as a scalar. So, if you see in vector form anywhere, do not be surprise, because it is a vector quantity. So, now if you, if you notice, if you go to previous slide, notice that, direction of dipole moment is always from minus q to plus q. So, this is something which you have to remember. So, what would the unit of this? The unit of this would be charges has coulomb dot meter. One must always be very careful about the units; if you want to make sure what you are doing is right, especially in mathematical formulas.

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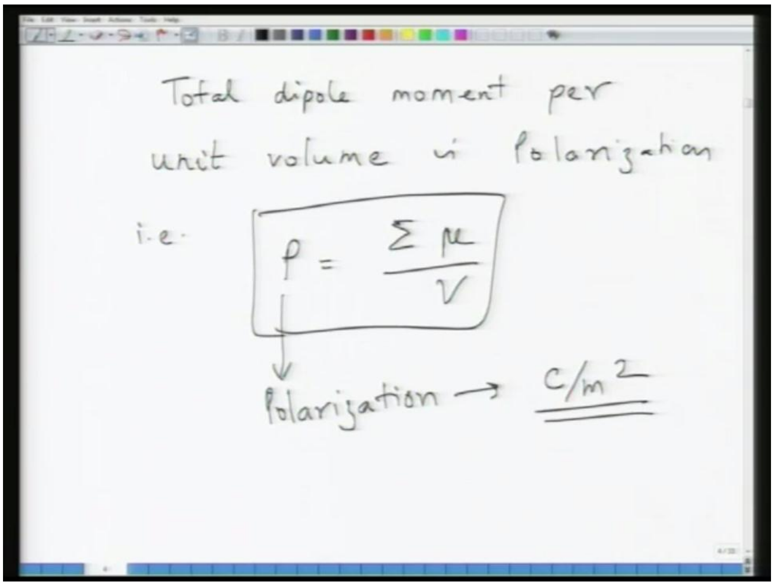

So, the total dipole moment, so when you generate a dipole moment the total dipole moment per unit volume is polarization, which is sigma mu divided by v. So, this is sum of all the dipoles in a, in a given system over its volume. And naturally, when you have so what is the unit of polarization? This p is polarization and its units are nothing but coulomb per meter square. Typically, you will see for most of the systems it is defined in, it is defined as micro coulomb per centimeter square. But it is just a sake of changing them but the units basically are charge stored per unit square per square per unit square of per unit square area of the material.

So, if you have, a let us say, you assume a system in which all the dipoles are aligned in one direction.

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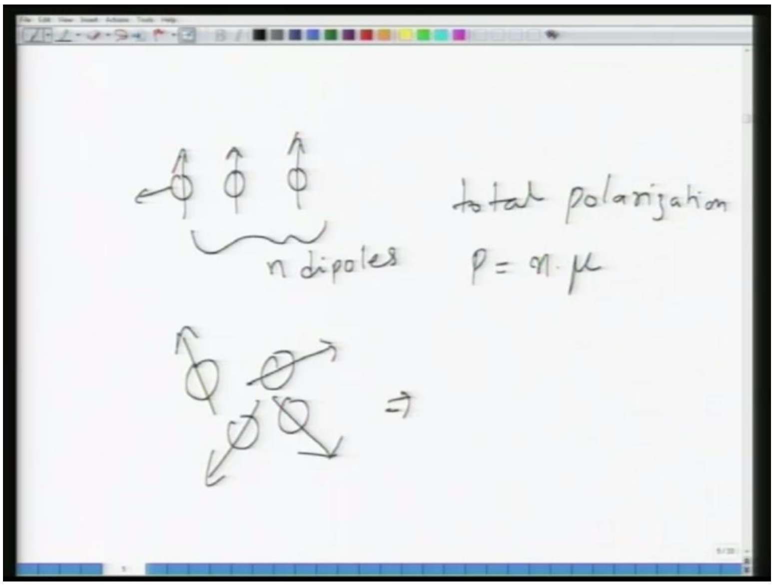

So, if you have a system like this, where you have one dipole like this, and another dipole like this, another dipole like this, so what this means is basically a charged dipole. So if you have a system like this, and you have n dipoles, then total polarization will be; p will be n dot n mu. However, if you had a system in which you have one polarization like this, another like this, another like this, another like this, so you get a situation where although each of the molecule or each of the dipole has finite dipole moment. The net dipole moment of the system is zero, because all this dipole moments are randomly distributed.

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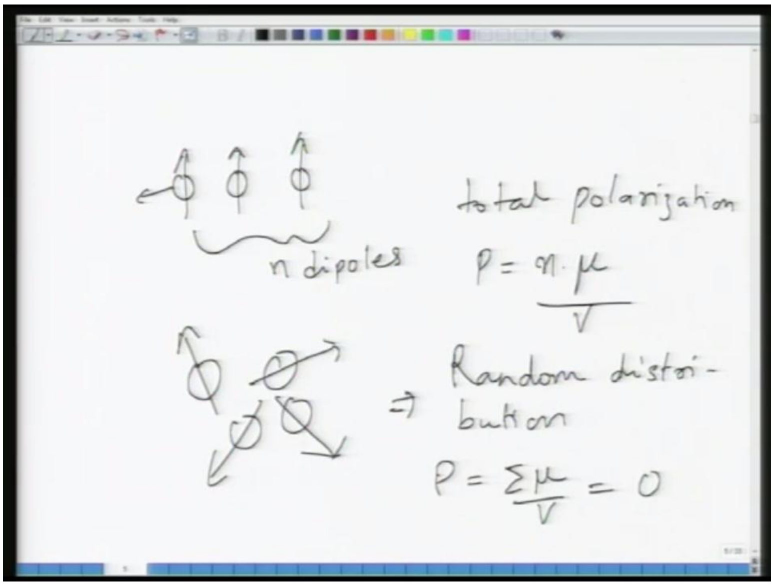

So, if you have random distribution, which often happens in polycrystalline material, then p is equal to sigma mu by v. This should be v divided by v; this should be equal to 0. So now, that is where you come across concept like, in which system you had dipoles which are aligned, in which system dipoles which are not aligned, we'll come to these concepts a little later. But on general sort of note if dipoles are aligned, then polarization is sum of all those dipoles, if dipoles are randomly distributed, then polarization is nothing but equal to 0.

Now, now the next thing that we will study is, we know now we have seen that polarization has units coulomb per meter square, which means polarization is charge per unit area. Now, what does it mean? So basically what polarization is?

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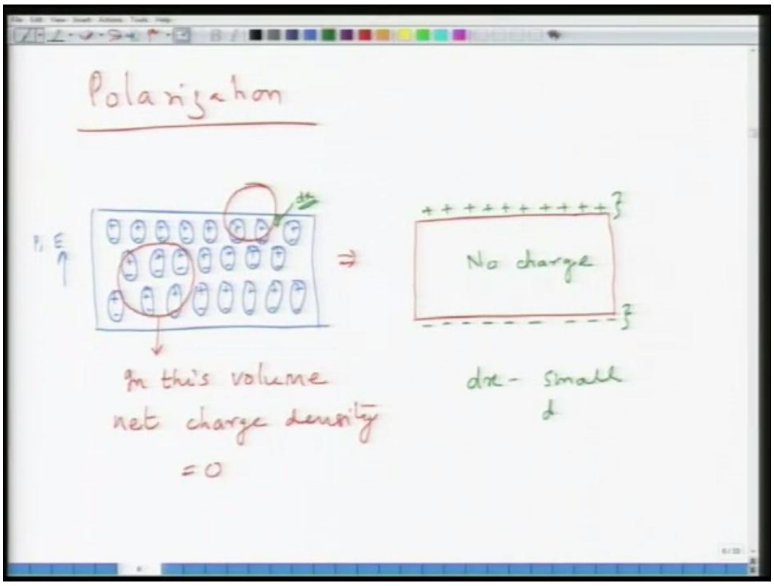

Polarization is nothing but so we will in this case, so polarization is nothing but surface charge, charge stored or charge on per unit area of a particular material system. So, let me just draw a particular schematic drawing, in which drawing of a material which is let us say polarized. So, you have this schematic material, in which you have these segments of the material, where you have polarization taking place. So, let us say this is situation is like this, each of this is charged dipole. So, naturally it is under the influence of electric field. So, what is the direction of polarization in this material? So, this is of course, the direction of electric field, the so e and p will be in the same direction.

So let us say I probe a particular volume in this material. I probe this volume in this material, so it is a circle or a sphere if it was a three dimensional. Now what is the next net charged density inside this volume of material? So, inside this volume, net charge density, as you can see, that in this circle, number of positive charges are almost equal to, are equal to number of negative charges. If you draw it perfectly, then this becomes equal to 0. So, inside the material, the net charge density is equal to 0, so net basically what it means is a net polarized, because positive charges cancel the negative charges.

However, when you look at the surface, if you look, here so within the materials volume, since positive number of positive charges are equal to number of negative charges. The net charge density is equal to 0. However, when you look at the surface, on surface you have finite amount of a particular charge and this probing volume; so this can be shown as, as if you have a scenario like this.

So, what we are basically saying is that within most of the materials volume inside, the material charge density is equal to 0. And since, only on the surface, the charges are polarized because of only the surface the material is polarized, only on the surface you have some finite charged density, because of polarization of the material. So, the situation looks like this. You have positive charge here, so this appears as if here you have no charge. And this is your surface charges and this is your surface charges. And these surface charges exist within a finite distance, very small distance what is called as d x.

So what we will do is that, what basically it is that, on a surface there is a finite charge and this finite charge as you can see in this tiny circle, they these finite charges move out with a small distance, let us say this distance is d x. As i shown here, so these charges move out by a distance d x. Now, what we will do is that, we will calculate this polarization on the surface.

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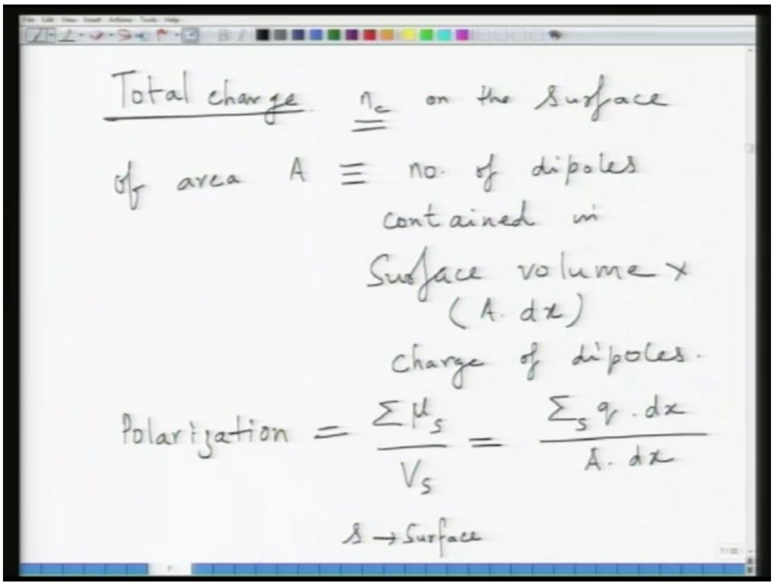

So, number of charges, so basically, number of charges n c, let us define it as, on the surface of area A. What will it be? This can be taken as equal to number of diploes contained on the surface, is on the surface, in that volume of thickness d x. So, what is this volume? If I take the surface area as A, then this volume will be a d x. So, a d x is the number of dipoles contained in this surface volume times the multiplied by the charge. So, number of, so basically, I can say this as, if I refine it little bit total charge n c, total charge n c on the surface of area a. Now what this is? This is nothing but equivalent to one layer of surface charge on the surface of the capacitor.

So assume that, we have this homogeneous distribution of dipoles on the surface, we can calculate what is the total polarization? So polarized now, assuming that they are homogeneously distributed, the total polarization can be written as, total polarization will be nothing but total dipole moment divided by the so volume. So, total so basically sigma sum of all the surface dipole moments, sigma mu s divided by v s. And what is and what is mu s? mu s is nothing but mu s is nothing but your sigma s q into d x divided by, where this subscript is nothing but surface, s refers to as surface. So and what would v s be? v s would be A dot A into d x.

So, is that clear? Polarization on the surface because of no charge inside the material, charges only exist on the surface of the material, because of non cancellation or because of nothing, because of nothing existing to cancel them on the surface, and they move out because of application of electric field by a little distance, as a result you create surface polarization. So what basically surface polarization is assuming homogeneous distribution of charges, a sum of total dipole moment on the surface divided by the total volume on the surface.

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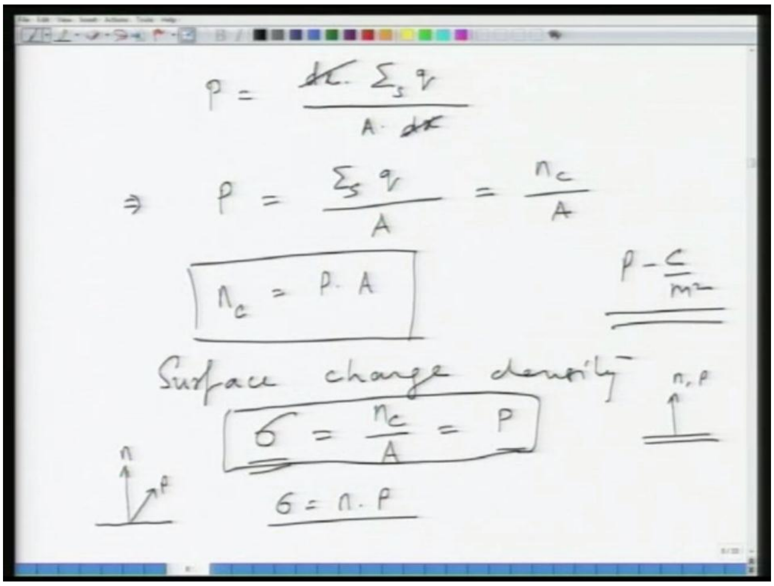

So, this is your polarization p. So, if this is the polarization p, so p can be written as d x sigma s q divided by A d x, d x d x cancel each other. So, as a result p becomes equal to sigma s q. And now which is nothing but total surface charge, and divided by a. So, total surface charge is what? n c divided by A. So, n c becomes equal to p by a. So, total surface charge is nothing but polarization multiplied by the surface area. So, the surface charge density sigma will be equal to n c by a, which is nothing but p. Now you understand what is the meaning of the unit of polarization? When we said, polarization is coulomb per meter square. It is nothing but your surface charge density.

So this is the key concept, if p dot moreover, if p is a p dot A is a scalar quantity then sigma would also be a scalar quantity. So but this is an important concept. The polarization that we have defined here is nothing but surface charge density, the area which is the charge which is within that particular area of the surface.

Now if the polarization, so we are taking sigma to be equal to p assuming that sigma and p are in the same direction, if this is your surface, if this is your surface normal, then p is also along this direction assuming that.

However, if your surface was this and if surface normal was this, and if p was that, this is your surface normal, and if this was p, then sigma would be n dot p, where n is nothing but the outward pointing vector which is normal to the surface of a polarized material. So, the key concept here is, what we have established here is, to look at the polarization little bit more deeply, and what we have established is, that polarization is nothing but polarization of a material is nothing but surface charge.

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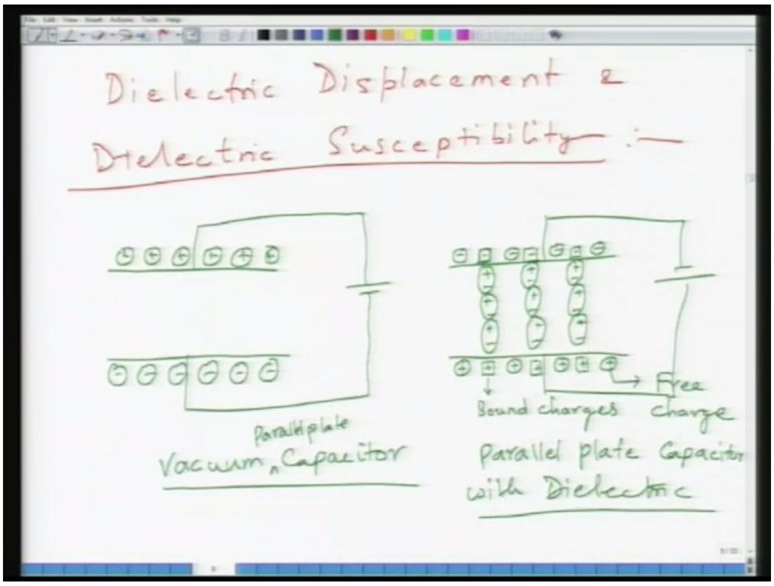

Now what we will look at some more dielectric, some more quantities which are related to the electrical materials and first of them are dielectric displacement and dielectric susceptibility. So you look at some of these key concepts. So what first we will do is that we will first consider a parallel plate vacuum capacitor, so what you have is a capacitor used different color for the sake of parity, so you take a parallel plate capacitor, which is which has charges like and this would happen only when you apply a field. So this is your vacuum capacitor.

Now, what happens when you take dielectric, when you insert a dielectric inside it, then the situation changes a little bit, so you still have the same maintain the same area and the same distance, and under the application of electric field so what you will have is a picture like this, now this is these are all schematic pictures so where as materials with different structures will give rise to different scenarios.

So, this is now so if it is a polarized material under the application of electric field, you have polarization inside the material. Now to compensate for these, you have charges on the surface, so you have, now these negative charges at the end of these dipoles would be compensated by positive charges on the surface, so these will be your bound charges. And then you have some free charges as well. And these circular ones are free charge. And likewise the situation is here.

So here, you have and this is of course, connected to a circuit. So, the situation is like this. So, this is a parallel vacuum, parallel plate. And this is parallel plate capacitor with dielectric. So, the difference here is, in case of vacuum capacitor, you do not have anything inside the dielectric, inside the between the plates, and what you have the surface charges, as a result of only vacuum and this is created when you apply electric field.

In case of parallel plate capacitor with the dielectric inserted, you have dielectric material inside the between the plates, which gets polarized when you apply electric field and this polarization of dielectric material causes modification on the surface charge density. And this is what gives rise to, what is called as electric displacement and something what is called as electric susceptibility.

So we will do further analysis in order to find out these quantities. So, and another thing just to notice in these, this image, this is nothing but your dipole. So, inside the material you have dipoles, which are polarized on the surface. You have two kinds of charges one is the bound charge, which is represented in a square. This bound charge is because of need to compensate the end of the dipoles. And then you have free charge, which is in circles which would be anywhere being present because it is not compensating any dipole.

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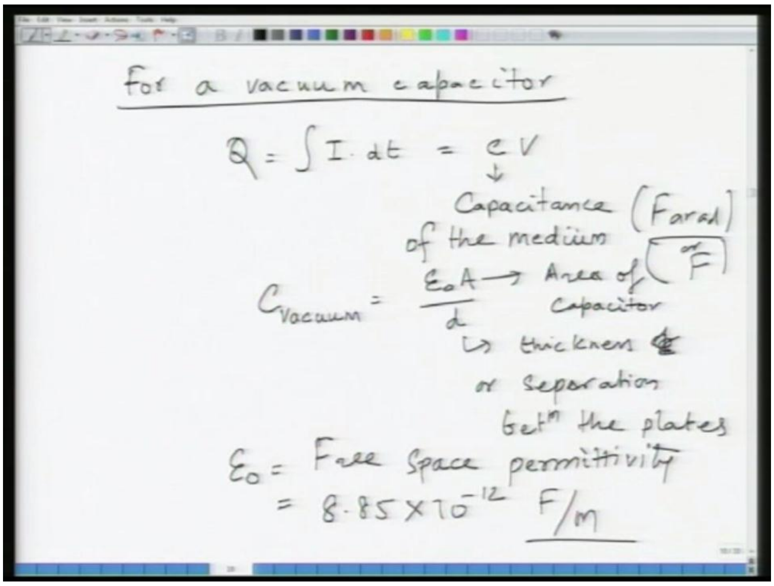

So the net, so for a normal vacuum capacitor, how do you write the charge? Charge inside the vacuum capacitor is nothing but integral of I dot d t which is nothing but c v, where c is nothing but your capacitance of the medium. In this case, the medium is nothing but vacuum. So, c for vacuum is given as epsilon naught A over d, where A is the area of capacitor, d is the thickness or separation between plates, and epsilon naught is the free space permittivity. And this is given as 8 point 8 5 into 10 to the power minus 12. So, the unit here is capacitance is defined in what is called as farad or f. So, epsilon naught would be farad here, farad per meter.

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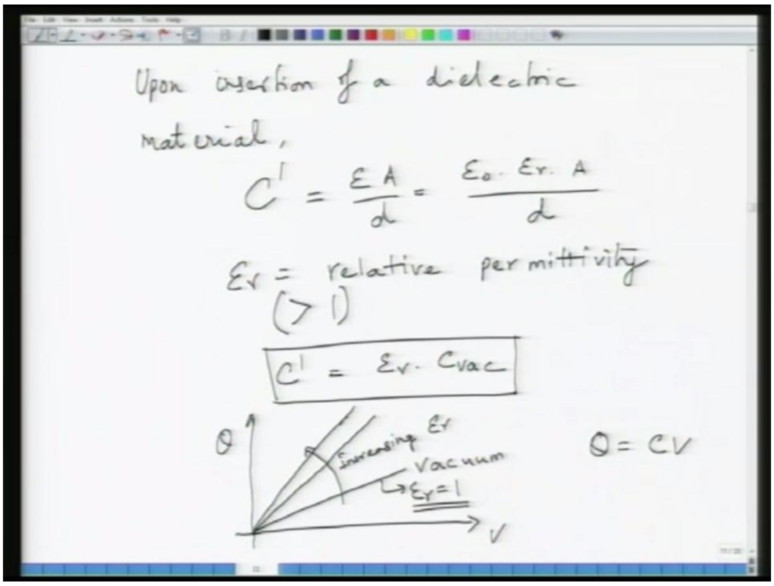

So this is the scenario for a vacuum capacitor. Now, if you insert a dielectric material between the plates, then the capacitance gets modified as so upon insertion of a dielectric material. This is the fundamental thing about dielectric material. A dielectric material when you insert between two plates, it has to increase the capacitance. So, the capacitance of so modified capacitance, let us say or C prime is equal to epsilon A over d, which is defined as epsilon naught, epsilon r a over d. So, epsilon naught A and d are same quantities, epsilon r is called as relative permittivity, and this has to be greater than 1 always, otherwise material is not a dielectric. So, the job of a dielectric material when it is inserted between two plates is to increase the capacitance of the material and that is because the epsilon r which is related to the material is always greater than 1.

So, C prime becomes epsilon naught, epsilon r A over d, as a result C prime is equal to epsilon r into C vac. So, basically what it means is that, when you put the dielectric material inside a vacuum capacitor, it increases the charge storage capacity of that particular capacitor. And so what it basically signifies, we do not really know but what it signifies at the moment is some sort of interaction between the material and the electromagnetic field. There is something happening at the atomic scale, which leads to or at the fundamental scale which leads to increase in the charge storage capacity and in which we will venture a little later in the module.

So, and what it means in terms of when you plot q versus let us say now, we know that Q is equal to C V. So, when you plot Q and C, so for a normal material, it goes like this. So let us say for vacuum it goes like this. What will happen when you insert a material? When you insert a material, it goes like that, so this curve shifts to right or this line shifts to left as you increase the epsilon of the material. So, this would, what this would mean is increasing epsilon r and this would mean epsilon r is equal to 1 which is nothing but your vacuum.

So now the question arises, why does increasing the dielectric material between a vacuum plate capacitor increases the overall capacitance. So, we will do that in the coming section or the coming part. So, now as a result of what we wanted to understand earlier was, we said we wanted to understand two fundamental quantities; one is the dielectric displacement and another is dielectric susceptibility. And what we discussed just now is a prelude to that understanding.

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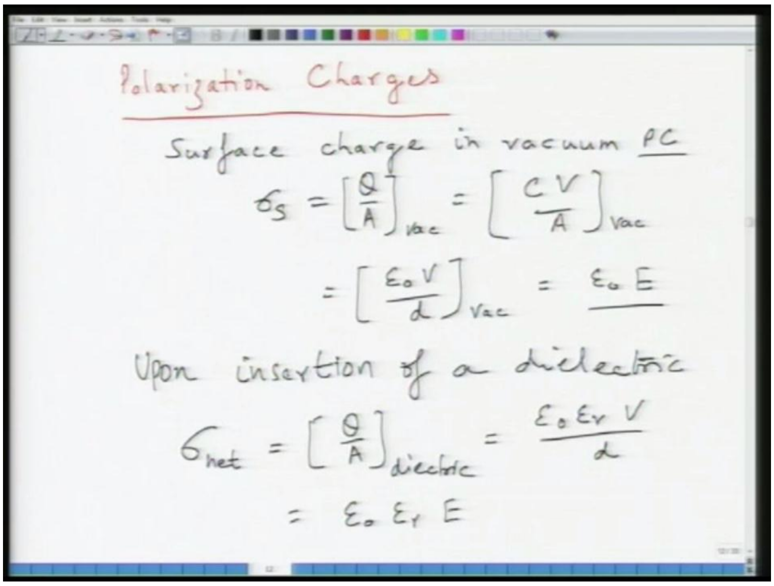

So, what we are now going to understand is, when you upon insertion of a dielectric is what is called as polarization charges. Now again we go to parallel plate configuration of the capacitor without any dielectric. So, in such a situation, what is the surface charge? So, surface charge let us say, in vacuum plate capacitor, let us say P C, Vacuum P C. Let us define this as sigma s. What is sigma s? Sigma s, I know is nothing but simple, it is Q by A of vacuum. So, if a charge density is a charge divided by area, and this is nothing but C V by A in vacuum and if I replace C with epsilon naught A over d, this becomes epsilon naught V divided by d vacuum, and this is nothing but epsilon naught E.

So, surface charge density in vacuum is equal to whatever the field which is generated because of potential that you applied, multiplied by epsilon naught. Now, what happens when you upon insertion of a dielectric? So, when you insert a dielectric between these plates, the as we know, if you go back to previous figure, so if you look at this picture, now when you insert a dielectric between this parallel plates what you see immediately is there is a modification in the surface charge density.

Now, what we are going to do now is to analyze this. So, when you insert a dielectric, the net charge density sigma net, which is the net charge density, now becomes so let us say, again it becomes Q by a dielectric which is fine. And this is nothing but your epsilon. So Q would be C V C would be epsilon naught epsilon r A by d A would cancel with each other so this would be epsilon naught epsilon naught epsilon r V by d and this would mean epsilon naught epsilon r E.

So, this would be the surface charge density, net surface charge density upon insertion of a dielectric, which as you can see it is more than the previous one, because here you have a factors epsilon r which is higher than 1. So, as a result, this net surface charge density is definitely higher than the surface charge density for a vacuum plate capacitor. So, that is what we are going to look at now.

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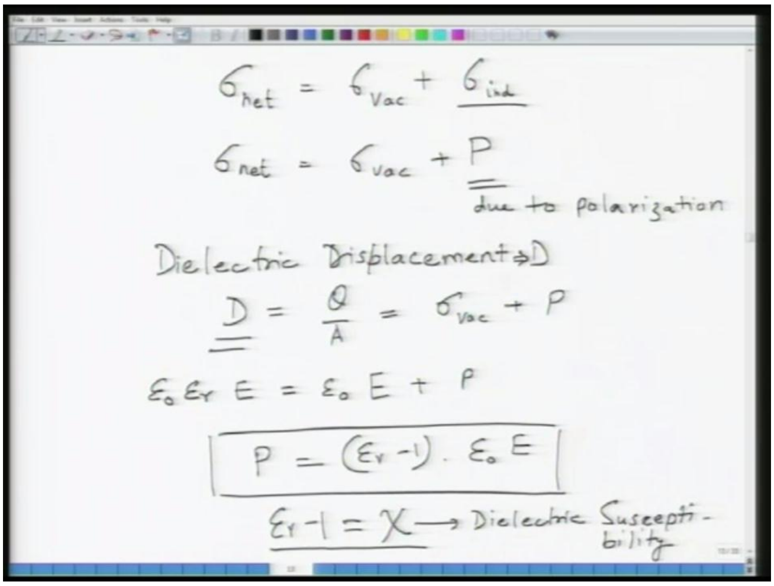

So, sigma, so this sigma net can be represented as sigma vacuum which was present without the presence of a capacitor plus something else. And what is that something else? Something else is which is coming from external, some external effect. Or, sigma let us say induced. This induced charges is, what we are interested in, what it is so sigma and this is nothing but due to polarization of dielectric. So, what we can write this as now sigma net is equal to sigma vac plus let us says rho. And this rho is nothing but due to due to polarization or is the polarization itself, because we know that, so we can what we can do is that we can just write this as P polarization. So, this is the extra charge which is resulting from the polarization of the material.

Now, according to electromagnetic theory, the surface charge on the plate of a dielectric can be defined as what is called as dielectric displacement. So, if we write this as dielectric, if we write it as dielectric displacement D, so this D can be written as Q by A. Now, so D for this kind of thing would be sigma vac plus P. And what is sigma vac we know epsilon naught E plus and P. And what is this, for the overall dielectric displacement this is nothing but epsilon naught epsilon r into E. So, this p polarization is now defined as, epsilon r minus 1 into epsilon naught e. This is what the polarization of the material is. Now you see the quantitative measure of the polarization.

So the equation basically, this equation shows that when you insert dielectric inside a when you in a between parallel plates, then the total surface charge density or the dielectric displacement gets modified by what is called as P which is nothing but polarization of the material. So, this is the fundamental equation, P is equal to epsilon naught e multiplied by epsilon r minus 1, since epsilon r is greater than 1, P is a finite positive quantity. So, and this epsilon r minus one is called as chi, and this is called as dielectric susceptibility.

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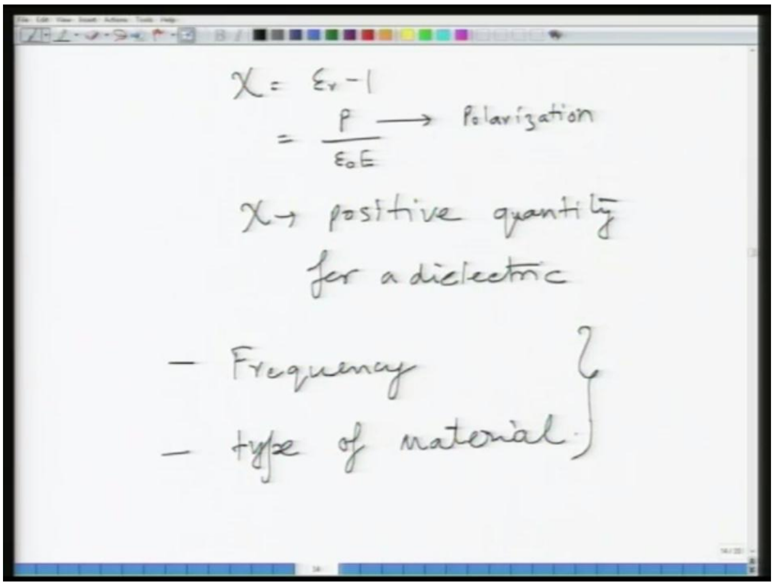

So, chi is equal to epsilon r minus 1, and what this would be equal to P divided by epsilon naught E. So, what basically dielectric susceptibility is, basically dielectric susceptibility is nothing but ratio of polarized charge. So, this P is nothing but polarization or polarized charge, divided by the charge surface, charge in a vacuum capacitor. So, polarized charge or the excess charge divided by the charge on the surface of the vacuum capacitor.

So, basically chi is nothing but a representative of response of the vacuum capacitor upon insertion of a material, and chi is always grater.

Then chi is a positive quantity for a dielectric material. So, what basically now in a nut shell, you can probably understand that, when the job of a dielectric is to increase the charge storage capacity of a parallel plate capacitor or a capacitor, and that is because it has it is characterized by a quantity which is called as a dielectric strength or relative permittivity which is always greater than 1. And this is because of polarization within this dielectric material which leads to this increase in the charge storage capacity and the response of the system upon insertion of this dielectric within this parallel plate capacitor is quantified by a quantity which is called as dielectric susceptibility. And this susceptibility because epsilon r is positive is always epsilon r is more than 1 it is always a positive quantity. This is a very fundamental easy but fundamental concept.

So now the question arises that is the, what are the mechanisms or what are the reasons of polarization? We said that, when we apply electric field, what could happen? We said that polarization is happening, but we still do not know why is polarization happening? What are the mechanisms of polarization? What will happen when we switch the field very fast? What will happen when we switch the field very slow? What will happen when we have a variety of materials? Because dielectrics could be variety of materials it could be amorphous systems, it could be crystalline systems, and it could be materials with different crystal structures. So, the questions there are variety of question which arises in order to understand this.

So, the key parameters which are important here to understand the electric behavior of a material is, what happens when you apply field of? So, most of the materials are used in a c field. So, as a result, what will be the effect of frequency of the applied field? So, this is one important thing. And then what would be effect of type of material?

So, these are some things that we will take upon in the next few hours that as we spent in this course. So, what we will, so what we have done so far is, we have, what we have done is, we have learnt, so we go from the beginning what we did was? We learnt the creation of a charge dipole in a material, and the moment you create a dipole. What it means is that the system gets polarized upon the application of an electric field. And basically, what it means is that, separation of positive and negative charges it could be now, what this could mean is separation of positive and negative charge within a smaller entity and it could be a large entity as well within the overall material. However, nonetheless the dipole moment is described as product of a magnitude of charge multiplied by the separation of charges, separation distance of the charges; as a result the units are always in coulomb meter. And this dipole moment when you sum it over a volume of the material, so total dipole moment per unit volume is what is called as polarization.

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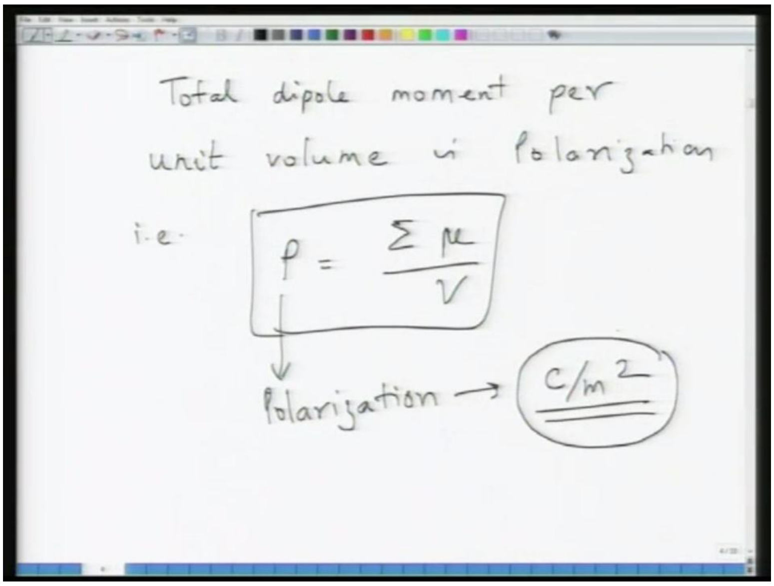

So this gives rise to a new quantity called as polarization, whose units are charge per into square meter. Now this unit itself raises enough curiosity about what polarization is? Then we looked at and of course, before we go further we can say very clearly, when you have dipoles aligned in one direction, in that case polarization is nothing but sum of all the dipoles or dipole moment multiplied by number of dipoles over the whole volume.

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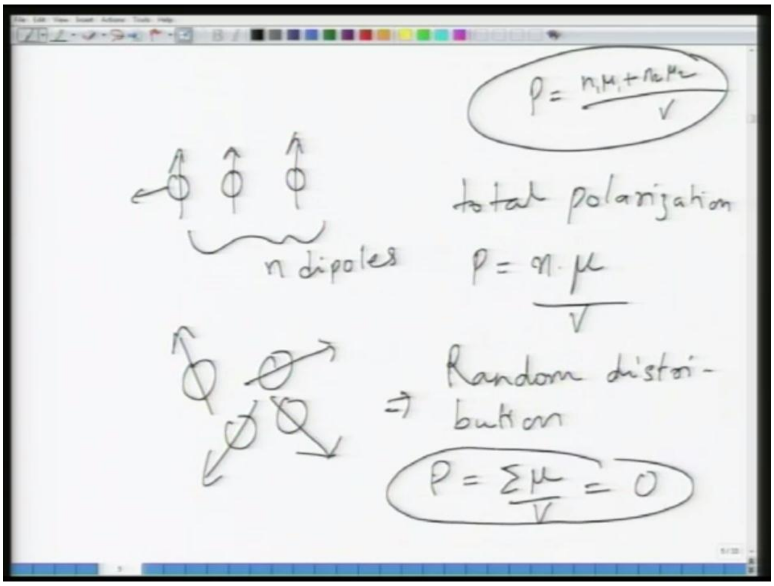

And if the dipole strength was different, then it would be P is equal to n 1 mu 1 plus n 2 mu 2 etcetera, divided by whole volume. So, this would be the case if the dipoles strengths were different in different parts of the crystal. But if you have random distribution of dipoles, then polarization is likely to be equal to zero. So, then we looked into what is the origin of polarization, so for that, we drew a schematic picture that so we took a dielectric material and assume that this dielectric material is polarized.

Under the polarized condition, we probed two volumes. We can probe inside the material itself, if you probe inside the material itself; we find that net surface charge density within that particular volume is equal to zero, because positive and negative charges cancel each other. However, when you probe at the surface, what you find is that, surface has a particular type of charge in excess and this excess charge gives rise to build up of charges on the surfaces and because of application of electric field these charges are because of creation of dipole moment, these charges are shifted by a small distance, let us say called d x.

So, from this what we worked out was the concept of polarization, which is nothing but your surface charge density as we found out later on. So, this sigma surface charge density is nothing but your polarization. And then what we did was we looked at the two configurations one is the parallel plate capacitor, without the presence of any medium that is in vacuum, and then what happens when you insert a dielectric.

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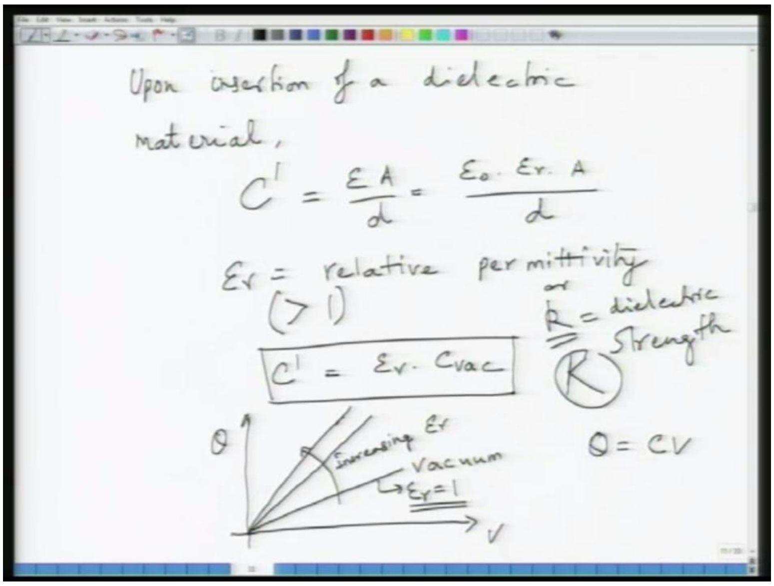

So, if you compare these two scenarios, what you come up with is a fundamental quantity for a material which is called as relative permittivity or sometimes it is also called as or some in some books also write it as k which is nothing but your dielectric strength.

So, it depends what you refer to or sometimes they write it as kappa. This is not very important; the important thing is you understand what it is, so epsilon r since when you that by definition when you insert a dielectric inside vacuum capacitor, it has to increase the capacitance. So, as a result epsilon r is greater than 1. So, what it means basically pictorially is, it increases the charge storage capacity of the capacitor and then we looked at the surface charge density mathematically, and from that we find out that the net surface charge density would be sum of the surface charge is that present in the without the presence of dielectric plus what is created without because of presence of dielectric and that is because of polarization.

So, from that we find two quantities; one is the electric displacement, which is surface charge density itself according to electromagnetic theory and which is nothing but sigma vac plus P. From this we find out another quantity which is the dielectric susceptibility which is epsilon r minus 1.

So basically, what you have to remember is epsilon r minus 1 or chi or dielectric susceptibility is a measure of response of the system upon insertion of a dielectric. And it is nothing but ratio of polarized charged or the excess charge to the charge on the surface of a vacuum capacitor. What we will do next is, to look at the reasons of polarization. Why polarization occurs? And this is very interesting, because this depends upon the frequency of an applied field, the frequency at which you are operating, and of course, it would also depend upon the type of material. So, we would look at it first qualitatively and then we will do the quantitative treatment of this whole exercise.