Advanced Ceramics for Strategic Applications

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Lecture - 17
Electrical Phenomenon in Insulators

Earlier we have subdivided or classified the whole range of materials in terms of electrical properties in different subgroups. Some of them are conductors, some of them are semiconductors, superconductors, and they are group of materials which are called insulators. It is expected that the electrical conductivity; in this insulators is very low or in other words the electrical resistivity is very high.

We have seen earlier that the electrical resistance is orders of magnitude larger than that of metals or semiconductors, but when we apply some electric field we putting in some energy; and therefore the materials supposed to respond to this electric field. So, today is topic is what happens when you apply electric field across a insulating material have been a very very high electrical resistance. Obviously there is no possibility of long-range charge transport. We do not get appreciable amount of current flowing through the materials that makes the charge, charges species are not moving over a longer distance.

However these charge species do respond to an applied field. And, let us see what exactly happens? Basically, the charge species moves within the material very small distance not the large distance or across the material. What happens in the conductor? So, there is no long range charge transport, there is a no long-range movement of the charge species. However there is a sort range movement maybe limited to the intra atomic spacing. So, within the intra atomic spacing, there is a movement of the charge species, but they do not break their bonds with the ion course. However, they change their positions and that is how some of the energy gets stored in this material.

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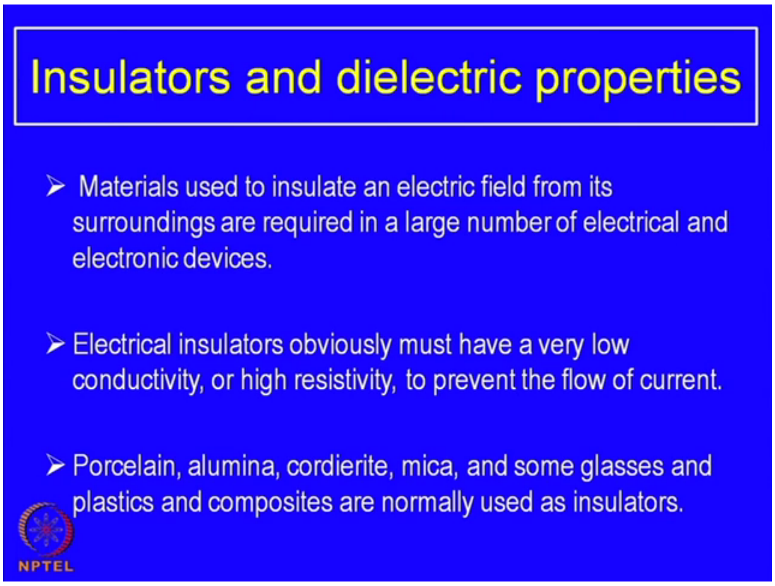

So, the insulators are basically from capacitors. And, if we look at the basic phenomenon what happens in an insulator when we apply electric field or in another words sometimes they are called dielectric materials. Here is a dielectric phenomenon which takes place; and that is what we want to discuss here. The materials used to insulate, but in general; since they have a very high resistance; they insulate from a conductor. So, if a particular conductor has to be insulated from another conductor or from its environment; these insulators act as an insulating barrier. So, materials to use insulate and electric field from its surroundings is equal in a large number of electrical as well as electronic devices.

In addition to dielectric properties, the simple insulation is also important. And, whenever you are using a semiconductor device on a or a conducting materials to insulate it from its surroundings a insulating material is quite useful. And, that is another function of an insulator electrical insulator obviously must have a very low conductivity, as I mentioned just now or very high resistivity to prevent the flow of current. So, there is no flow of current. Ideally a insulators should have a 0 current or infinite resistance, but in reality there is always a finite amount of current flows through it. Sometimes it is called a leakage current and that can be measured also with different kinds of instruments.

The examples of some of these insulators as we have seen earlier once again can be repeated here. The porcelain basic insulators, clay base insulators or clay base ceramics aluminum oxide, aluminum cordierite is another important insulating ceramics. And, mica is a natural mineral and also a one of the ceramics that is the layer kind of ceramics and some glasses of different compositions sum glasses of course fairly conducting. Whereas, most of these glasses are insulators and of course there is a range of plastics, polymers which are in general insulators but maybe you are aware that there are examples of plastics or polymers which are also conducting in nature.

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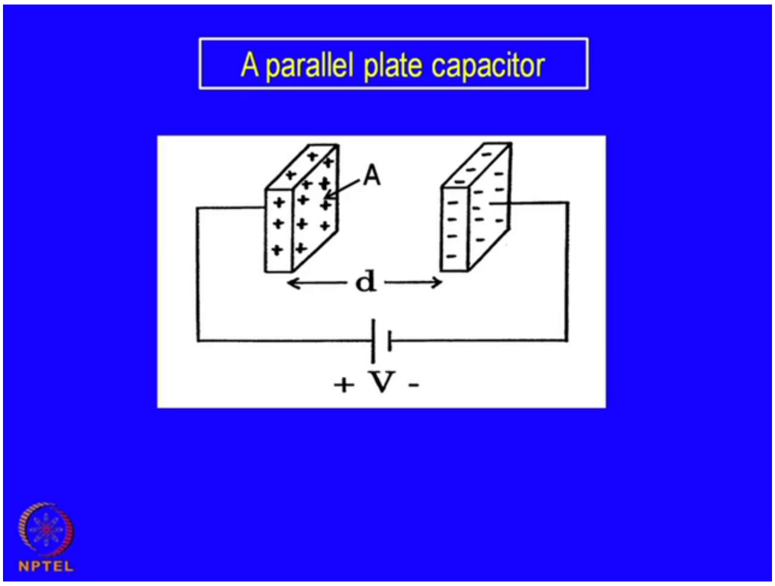

So, we are talking about basically different kind of insulators. And, a one of the best way to understand what happens when a insulator is under electric field is to look at a capacitance or capacitor. Capacitor is a very simple device where we have 2 metal electrodes one is positively charged and negatively charged and in between we have a gap. And, that gap may be filled up with an insulator; even air is a good insulators very good insulator. So, between the metal between the 2 metals if there is an insulator that can be called as capacitance capacitor and we have some important parameters of this device as well as the materials.

So, here is a example of a what we call it parallel plate capacitor. It is as the diagram shows that we have a positively charged conducting plate, on other side negatively charged conducting plate and the gap is above d spacing is d and the area is a. We apply a voltage v across this 2 electrodes. And, the charge which can be stored charge is not flowing away the charge can be basically stored the total amount of charge stored is equal to c into v; c is the capacitance of that system device and the o v is applied voltage. This gives rise to a few more equations like v equals to q by c; and that is equal to integration i dt by c, because charge is nothing but the accumulation of total. This is the total charge over a period of time flowing in the form of a current.

So, the total current flow over a period of time gives you the total charge which is accumulated or flown across the 2 electrodes. And, c is the capacitance of that it is a device parameter and it is a has some unit which we will discuss in a few minutes. It also gives rise to another equation in terms of i the current flowing through the capacitance or capacitor ;although we say is an insulator but there is a current sets up within the material. It is not flowing across the material, but there is some current flowing because charge is getting accumulated. And, therefore, flow of charge is nothing but the current so, that current is given by i equal to c d v d t; the derivative of voltage with respect to time.

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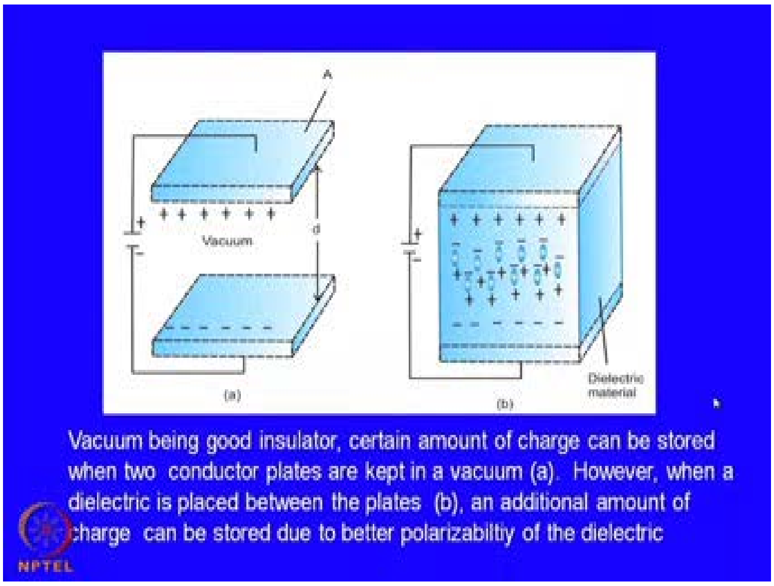

In fact we will look into another situation another 2 pictures here. One is the same thing what we have shown earlier it is in between we have a free space one is positively charged plate and the negatively charged plate. And, in between we do not have any material here it is evacuated. So, vacuum or free space. So, that also gives rise to some kind of a capacitance value and charge accumulation. However in the right we have a material we have a solid is basically an insulator if it is a conductor then charge will be flowing from one electrode to the other.

So, we are not a conductor cannot be used obviously for charge accumulation or forming a capacitor. Therefore, we have an insulating material in other words it is called a dielectric material. So, all the insulators have a dielectric phenomenon and that is what we are going to discuss here. So, there is an accumulation of charge, but there is an redistribution of charge. So, whenever there is a material; insulating material some changes do take place within the charge distribution or so far as the charge distribution of within the volume of material is concerned. And, how it is done that will discussed? So, initially we have one situation where there is a vacuum; vacuum being an good insulator certain amount of charge can also be stored when 2 conductors plates are kept in vacuum.

That is way however when a dielectric is placed that vacuum is replaced by a some kind of insulator; and additional amount of charge can be stored due to better polarizability of the dielectric. The term polarizability will explain in a few movements. So, there is a difference between a situation where is it vacuum in between the 2 electrodes; and there is an insulator or a dielectric medium we call it dielectric medium. So there is more effective charge accumulation or energy storing capability whenever there is a good insulator. So, that is what it been shown here. We can see we can see some more equations like this.

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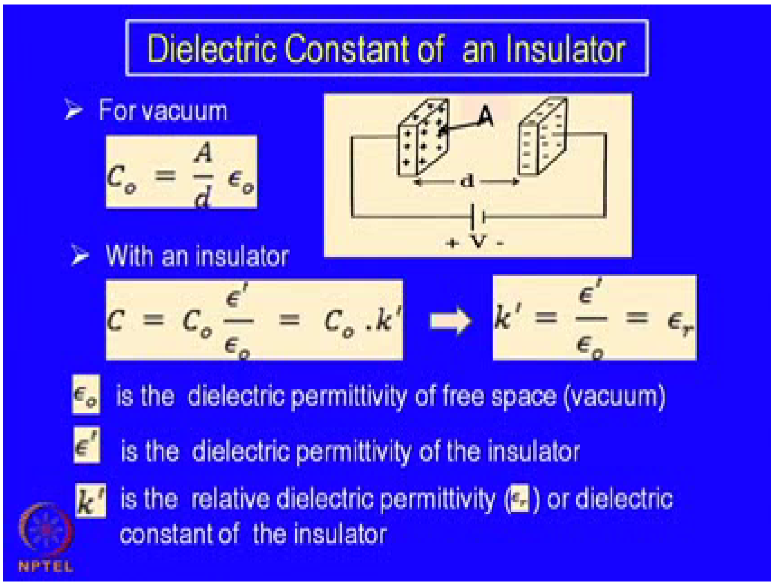

The same for the vacuum whatever equation we have written earlier is c 0 the capacitance is a geometric function. So, it is A by d; a is the area, d is the distance and introduced a term epsilon naught; epsilon zero multiplied by A by d that is the capacitance of the simple device. So, if you have a vacuum then vacuum has some kind of insulating property. And, that is characterized for the dielectric property is characterized by epsilon 0 which is known as the permittivity permittivity of the free space it is a constant. And, we will come across this particular term in repeatedly during our discussion.

However if you have a insulator as we have shown earlier earlier picture c changes to capacitance; capacitance with the insulating material in plus so c 0 epsilon prime by an epsilon naught. So, epsilon naught once again is a permittivity dielectric permittivity of the free space and it is a constant. And, c 0 has been defined earlier in the above equation in the previous equation. And, so c 0 multiplied by epsilon naught by epsilon prime by epsilon naught where epsilon prime is the permittivity dielectric permittivity of the material which we have placed which replaces the vacuum. So, you have a overall capacitance with a insulator in place in c 0. C 0 is been defined above and k prime.

K prime is the relative permittivity or in other words k prime is equal to the epsilon prime by epsilon naught. And, sometimes also represented as epsilon r; the relative permittivity or k prime when we write k prime is also called the dielectric constant. So, dielectric constant k prime in some places one can see also only k, but k prime is better representation that would be clear when we discuss later. Why we are using k prime? But in many literature you also find k just k has the dielectric constant and epsilon r is a relative permittivity which are basically the same quantity. This dielectric constant is a material parameter and it does not depend on shape and size of the material.

But it depends on the structure of the material the composition of the material and the particular type of bonding; chemical bonding it has. So, k is a material parameter of very importance and that is how one can characterize a dielectric material. So, ones one somebody wants to design a capacitor a particular value. And, charge storing capacity of a particular system or device k prime or k dielectric constant of the material is a very at most important prime importance. So, that1 can design what kind of capacitors can be fabricated out of that. These are just the definitions of the different parameters used here. Epsilon 0 is the dielectric permittivity of free space vacuum, epsilon prime is the dielectric permittivity of the insulator and k prime is the relative permittivity dielectric permittivity or the dielectric constant of the insulator.

So, it is also the same as epsilon r, k prime and epsilon r are actually the same quantity they have been used different context.

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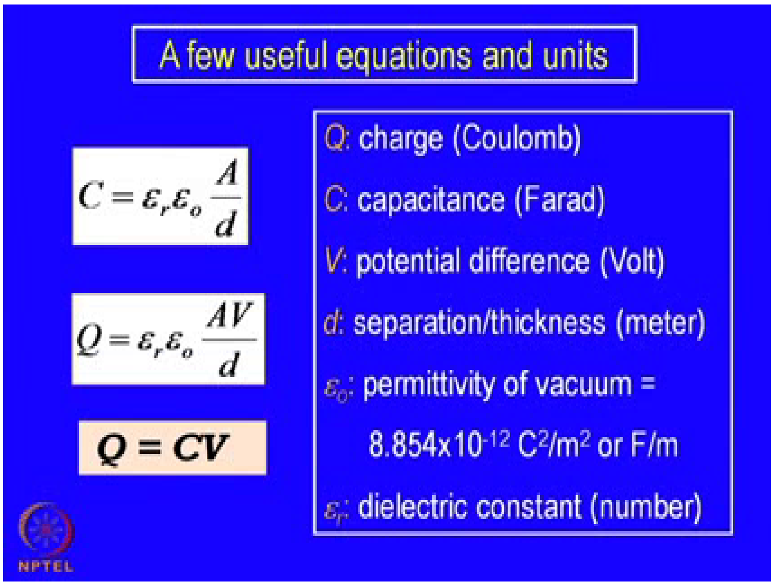

Few important equations once again and some of the units. capacitance is just what have been indicated epsilon r epsilon naught A by d. A by d is the geometric factor of the capacitance and q the charge accumulation is epsilon r epsilon naught AV by d because basically q equals to c v. So, this part c and this part is c v and so that once again the same equation has been written here.

Now, the units. Units of charge are known is nothing, but coulomb? And, capacitance is farad, v is a potential difference in volt, small d is the separation or the thickness of the insulator and it in a meter, epsilon naught which is a constant term. It is a permittivity of the vacuum or sometimes called permittivity of the free space and the value is 8.854 into 10 to the minus 12 coulomb square per meter square or farad per meter. So, farad per meter is a more common unit which is used and epsilon r in the dielectric constant. It is nothing but it is a relative number and it does not have any unit.

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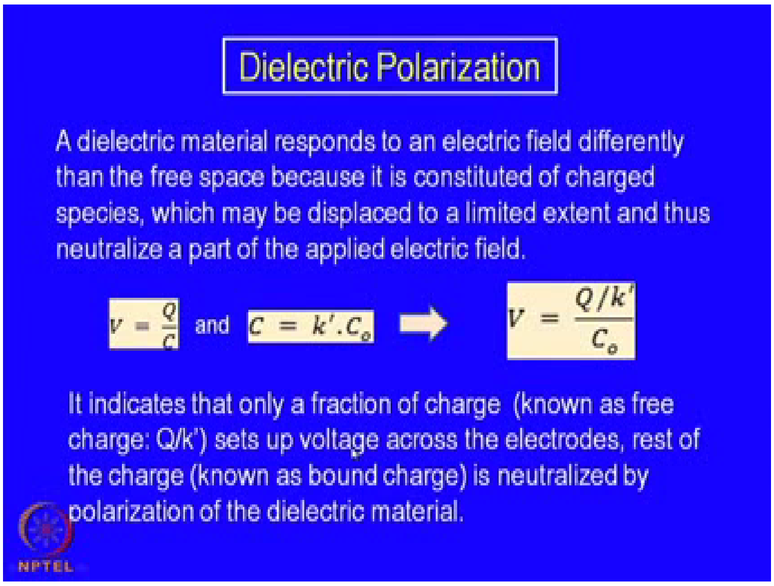

Next we look at what exactly happens in an atomistic scale; when we apply an electric field against an insulator. So, dielectric material responds to an electric field differently than the free space because it is constituted of charged species; free space does not have a charge species. So, the permittivity is much less. So, therefore when you apply electric field against a insulator; which is having a charge species. Some of the charge species may be displaced to a limited extent thus utilize the part of the a paired electric field. So, as I mentioned earlier whenever we apply a field electric field or an energy the material the internal structure of the material internal constitutions of the material respond in a particular manner.

In case of conductor the free electrons of the free charge carriers moves over larger distances from one end of the solid to another, one of the medium to another medium to another end of the medium. Whereas, in an insulator because they cannot move a longer distance and that is the property of an insulator. So, they move to a limited extent. So, they do change their position geometric position, but very very limited extent. And, that is the characteristics of a particular material and the particular structure, particular chemical bond it has and so on so far.

So, once again we can have this kind of there are more or less are the same equations has been written slightly differently. So, starting with V equal to Q by C; and C is equal to k prime c 0. C 0 is the capacitance where vacuum of particular geometric configuration these 2 give rise to these 2 equations give rise to another equation which is v equal to q by k prime q o by k prime by c naught or c 0. So, you have basically a ratio of q by k naught by c 0; c 0 is the capacitance of the vacuum. So, it indicates that only a fraction of the charge known as the free charge which is q by k prime.

So, this is k prime is the number. So, q prime is some fraction of q sets of voltage across the electrodes and rest of the charge known as the bound charge is neutralized by the polarization of the dielectric material. So, there are 2 different forms of charge or 2 different kind of situation happens simultaneously of course and one forms the bound charge and there is a free charge. So, free charge free charge which is what q by k sets of the voltage across the capacitor. Whereas, the bound charge actually does some internal rearrangement of the charges and neutralized and gets neutralize by that process.

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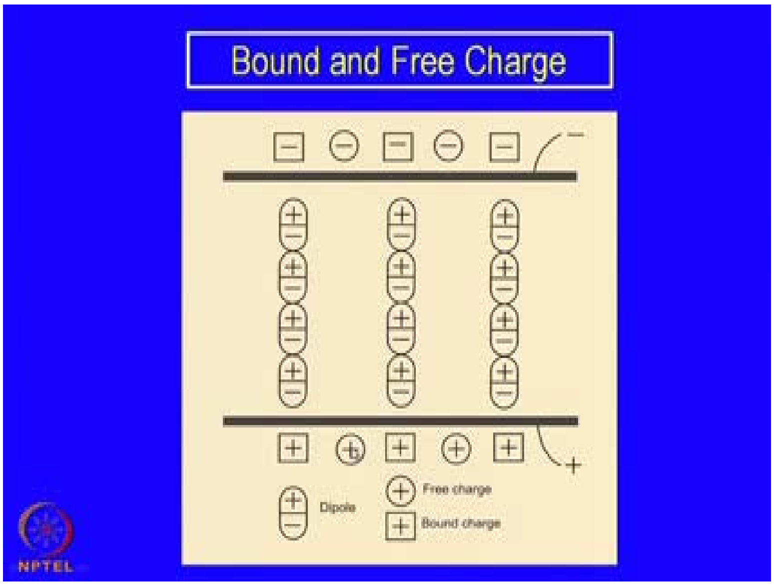

So, these can be seen here bound and free charges. This is 2 parallel plates or the electrodes these are conductors one on the top, one on the bottom. And, we are applying a negative charge or negative potential on the top and the positive potential on the bottom electrons. So, these are the charges available within the insulators; within the between in between the 2 electrodes we have some charges already present in the material. They get reorganized they get reorganized when we apply electric field. So, we have 2 types of charges 1 is with the square all are negative charges of course but 1 is a square, another is sought wet. Here also all of them are positive charges because is a connected with the positive potential.

So, you have 2 different kind of charges; 1 is encircled a square, another is circle. Now, you can see here these positive charges have a corresponding negative charge inside the material. And, then that is neutralized by another positive charge. So, there is a realignment there is a realignment of the charges against this positive and negative charge. So, you have whatever positive or negative charges were present either in the form of cations, anions or maybe the electrons as well as protons. So, all of them to realign themselves against the electric field and some of them will be neutralized. So, these are the bound charges.

So, these charges inside whatever charges inside the material are used they will mind some charges on the surface of the electrodes. So, on these side the negative charge will be bind by this positive charge, and on this side this negative charge will bind this positive charge. So, that way there will be realignment of positive and negative charges and each of them actually forms a dipole. So, these are formation of dipoles that means a positive and negative charge separated by a distance. So, these are as a result of the application of the electric field your generating some dipoles within the insulator. And, these dipoles are binding some charges on the surface of the electrodes.

However, all the charges available on the surface of the electrodes are not bound by the dipoles created or generated within the solid. Only fraction of them will be bound and others will remain free and that is what it is shown here in the same diagram. These are free charges; circled ones are free charges there is no corresponding dipoles on this side. So, these are free charges which actually develop the voltage on the plate or the metal plates. metal electrodes. And, these are the changes which takes place within the solid. So, you have 2 types of charges on the surface of the plate.

One is the bound charge and another is the free charge. So, that is what has been described earlier it indicates that only a fraction of the charge known as the free charge. Which is given by these sets of the voltage across the electrodes, rest of the charge known as the bound charge is neutralized by the polarization of the dielectric material.

So, this is what we call basically the polarization. That means, creation of some dipoles within the material. Initially we will find later on that this charges might not be forming dipoles or they are not bound to each other. So, they are more randomly distributed of course in a crystal there are certain amount of periodicity but they may not be aligned to this. So, this alignment and formation of the dipoles actually the phenomena is called the polarization. So, when you apply an electric field against a insulator the charges gets polarized and that polarization is what we call the dielectric polarization.

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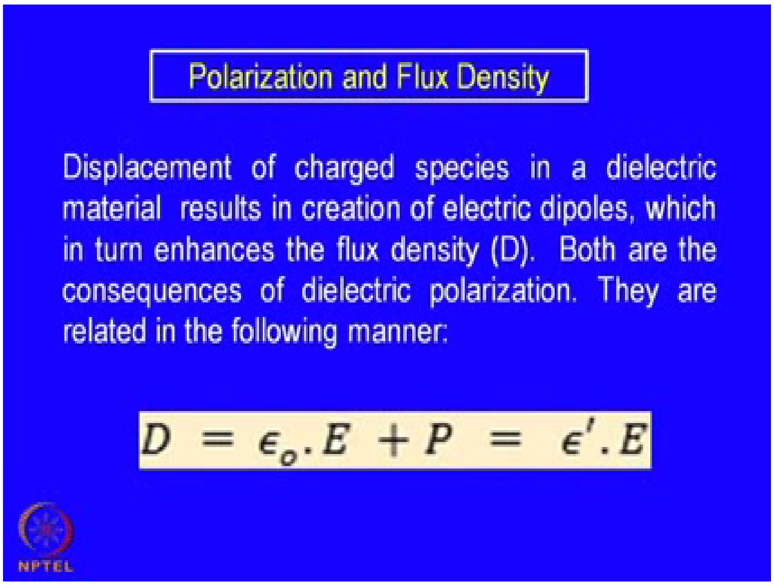

So, this is an important phenomenon of a dielectric material. So, polarization is a very common phenomena and very important phenomena whenever we are talking about a dielectric material. And, its electric field is applied against it. So, polarization flux density displacement of charge species in a dielectric material results in creation of electric dipoles. That is what I have been discussed which in turn enhances the flux density. So, it is called the dielectric flux density both of the consequences of dielectric polarization. So, they are related in the following manner. So, we have 2 terms one is the polarization term, another is the dielectric displacement or flux density.

So, these are the 2 terms of the related D the displacement or the flux density is equal to epsilon naught again the permittivity of the free space comes in multiplied by the electric field. Electric field not the voltage at the electric field plus polarization; p is called the polarization. So, dielectric displacement of the flux density is equal to epsilon naught E plus polarization and that is all nothing, but epsilon prime multiplied by E. So, actually dielectric displacement is D equal to epsilon prime multiplied by E and this is again equal to epsilon naught into E plus p; p is the polarization. So, this is the 1 can see these is the polarization of the free space and this is the polarization of the insulating page or the dielectric material in between.

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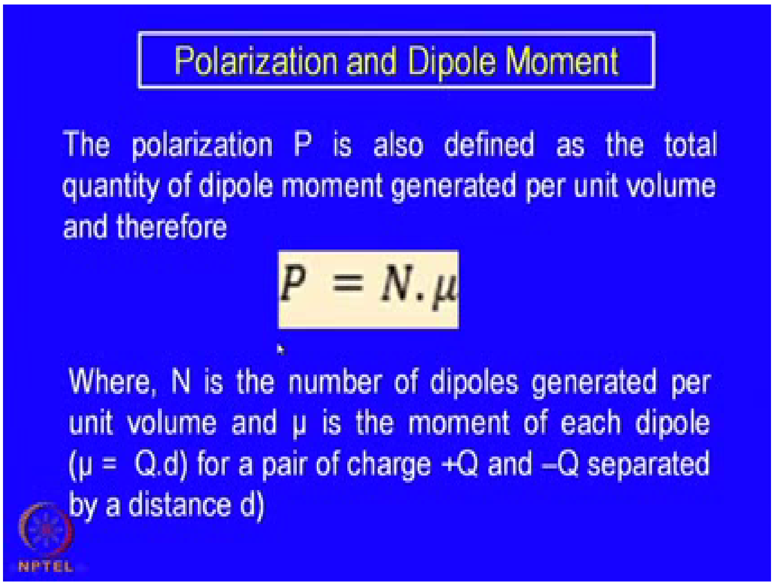

So, this is the relationship between the 2 parameters will also have a relationship because polarization is the result of creation of dipole moments within the material. The polarization P is also defined as the total quantity of dipole moment generated per unit volume of the material. So, that is the polarization P is equal to N multiplied by mu; N is the number of dipoles generated per unit volume and mu is the dipole moment. The moment of each dipole mu is also given by Q into d where q is the pair of charge; that means 1 is a positive charge another is a negative charge the same magnitude. So, plus Q and minus Q separated by distance d gives you the dipole moment q into d.

So, that is the dipole moment mu. And, how many dipoles are created how many dipoles are created? And, what is there moment dipole moment? And, what is the total number of dipole moment? N is the total number of N is the number of dipoles generated per unit volume. So, per unit volume whatever the total number of dipoles the dipole moment generated that is the major of polarization. So, higher is the dipole moment creation higher is the polarization, higher is the moment dipole moment for each of the pairs that also create more dipoles. If Q increases P increases; if d increases also P increases. And, if n increases or n is more P is also more. That means, how many dipoles are getting generated?

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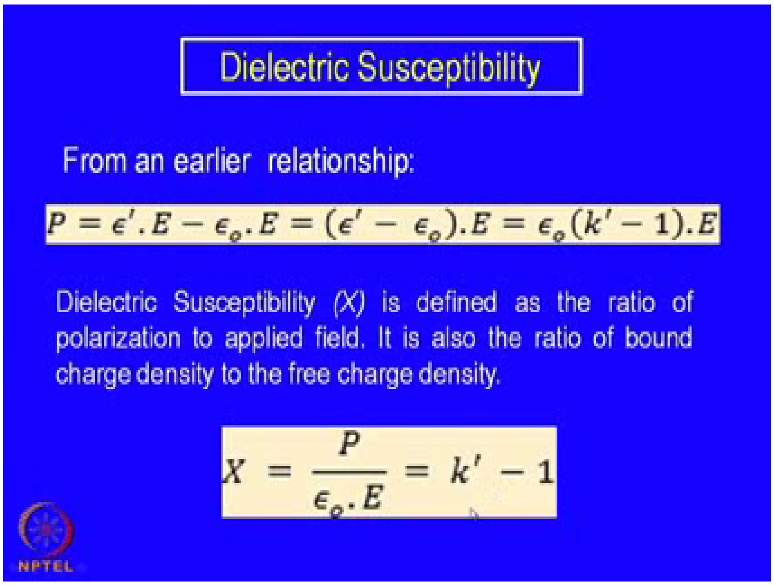

There is also another parameter used in dielectric literature that is dielectric susceptibility. From an earlier relationship these are rearrangement of those equations earlier used P equal to epsilon prime E minus epsilon naught into E. So, P is actually the parameter related to the insulator or the dielectric material. So, this is the total effect that is the epsilon prime into E subtract from that above the so called the vacuum. So, if you if you subtract the magnitude or the quantity of the polarization from the vacuum that from the overall polarization; that is actually the polarization of the solid.

So, that can also be written in these form epsilon prime minus epsilon naught into E. And, since there is a relationship between these and k. So, if you it can be written as epsilon prime with in bracket k minus k prime minus 1 into E. So, this is what we can know by rearranging the earlier relationships we have used. So, the dielectric susceptibility actually it is khai its not x it is khai is defined as the ratio of the polarization to the electric field. It is also the ratio of the bound charged density to the free charge density. So, khai is actually we have discussed few minutes back about the bound charge and the free charge.

So, that ratio is also is actually the dielectric susceptibility another parameter used in dielectric literature. So, khai is again defined by polarization total P by epsilon naught E. So, this is for the vacuum and this is for the material. So, P by epsilon prime E equal to actually k prime minus 1. So, it is the dielectric constant minus 1 is just the dielectric susceptibility. So, there is a simple relationship between the dielectric susceptibility and the dielectric constant. So, it is the 1 less than the dielectric constant or relatively dielectric constant.

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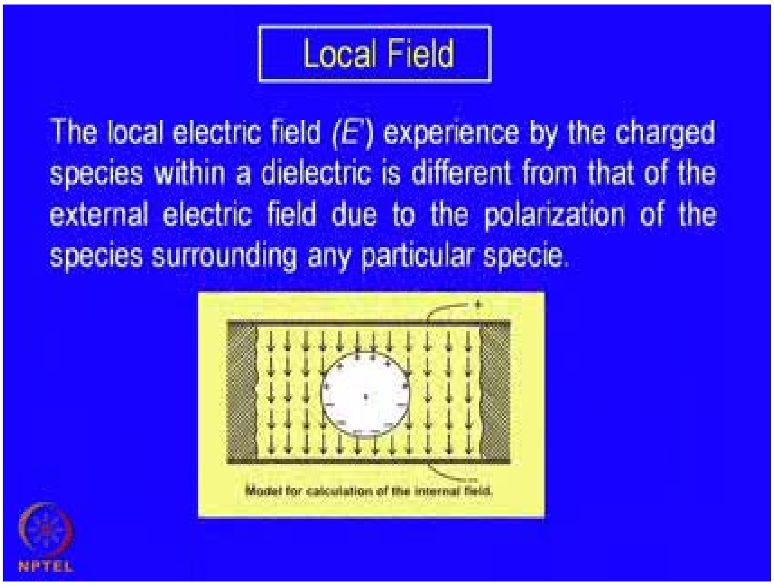

Now, there is a also a concept of local field local electric field experienced by the charged species within a dielectric is different from that of the external electric field applied from the outside. Due to the polarization of the species surrounding any particular species. What if you want to find out what is the electric field experienced by this particular charged species? When a electric field E is applied from outside? So, this is once again a parallel plate capacitors this are the 2 electrodes; 1 is positively charge another is negatively charged and we are applying a field E. Now, this inside the material a particular charged species what it is experiencing is not exactly equal to the E is actually E prime which is slightly different from what we measure from outside.

So, that also have to be considered while we are talking about what is happening inside the material? So, that is what it is called the local field. Local field is different than what we apply from outside? And, that is because all these things are dipoles. Dipoles have already been generated and they have some create some internal field; in addition to the external field. So, the external field generates these dipoles. And, these dipoles as an influence on the neighboring dipoles or neighboring charge. So, as a result the particular point any charge species experienced or the field experience by these charge species is different from what we apply from outside.

So, when we are trying to calculate what is the polarizability? And, what will be the dipole moment and so on? One is to take care of this kind of the situation. We are not going to be details of the calculation but only it will be convenient to know that this dielectric, this electric field is different from that applied from the outside. And. that is called the local electric field E prime normally it is called E prime which is different from E.

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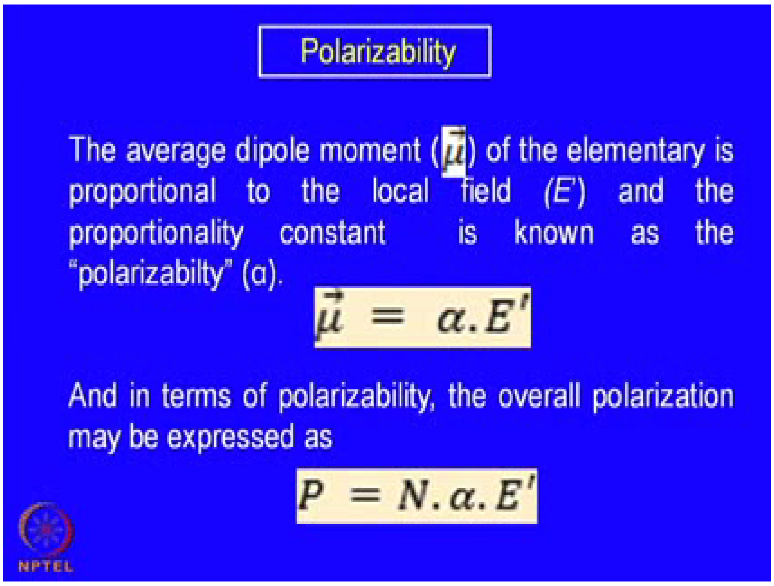

So, that is another situation one has to keep in mind. With this in mind if you want to try find out a another parameter which is called polarizability; that is the ability of the material ability of the material to get polarized. So, that is what we call the polarizability. And, that is defined this manner the average dipole moment which is mu bar of the element of the elementary particle is proportional to the local field So, the average dipole moment mu bar of the elementary particle or the elementary dipole is proportional to the local field E prime which we have just discussed.

And, the proportionality constant is known as the polarizability or the alpha. I think there should be change it this should be elementary dipole is proportional to the local field E prime. And, the proportionality constant is known as the polarizability with a with the parameter like alpha. So, mu bar is proportional to the E prime not E that is the only thing one has to remember it is not E. E is the external field normal applied and E prime is the external is the internal field or the local field experienced by this particular element or dipole.

So, and the proportionality constant is the polarizability. And, it gives a an idea how easily or difficult it will be to polarize a particular material. So it is a against once again a material parameter. And, in terms of the polarizability the overall polarization will be expressed as a P to n alpha E prime. So, once again the polarization total dipole moment. So, this is the dipole moment for each elementary dipole and these are the number of dipole per unit volume. So, a once again in another way P can be expressed in terms of the polarizability; another material parameter of any particularly material.

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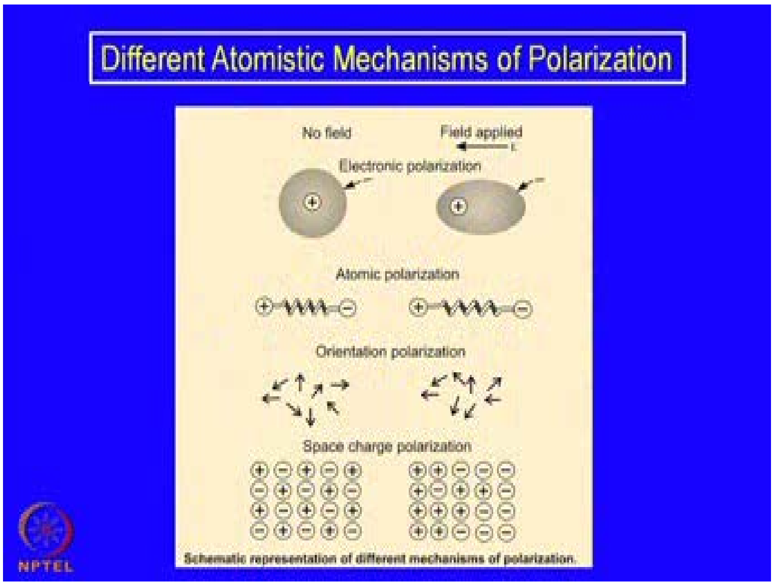

Well with these (( )) description of what happens when we apply an electric field against an insulator? What happens what kind of dipoles created? Basically there is a polarization there is a more number of dipoles are created. And, that dipole give rise to dipole moment and the polarization is basically measure of how much dipole moment it generated per unit volume? So, ultimately when we apply an electric field to an insulator instead of a large range conduction large long range conduction or large range moment of the charge carriers. There is formation of a dipoles some amount of reorientation of the charge distribution, redistribution of the charges takes place in inside the material and that absorbs the energy that absorbs the energy and therefore, the energy the electrical energy get store inside a capacitor or in a within a dielectric material.

Now, there are different mechanisms by which these dipoles can be generated. Dipoles as you can understand it is nothing but 2 charges one positive charge another is negative charge separated by a distance and that distance is so that has been separation. So, the centre of positive charge and the centre of negative charge must not coincide. So, initially in a solid in a solid or liquid the centre of positive charge and centre of negative charge normally coincides. And, therefore, there is a no net distance of separation. So, dipole moment is zero that is the normal concept but when we apply an electric field and there is a distance of separation.

The net distance of separation the centre of positive charge and centre of negative charge distribution throughout the material gets separated and you form a dipole. And, that is what has been given here there are 4 different mechanisms distinct mechanisms by which there is a distance of a dipoles can be generated. This is the first one is called electronic polarization, second one is called atomic polarization, third one is called orientation polarization and the fourth one is called space charge polarization. Let us see what exactly mean by this terminologies. On the left we have a situation when there is no field. So, it is equilibrium situation there is no field is applied, on the right the situation when a field is applied.

Now, in this we can see there is an electron within electronic when we are considering electronic polarization we are focusing our attention with the 2 each individual atoms. Each atom has a positive core or a nucleus around which there is an electron cloud. There is an electron cloud large number of electron clouds are moving around the positive core. So, that is the iron core and around that is the electron cloud. So, this is negatively charged and this one is positive center is positively charged. So, centre of the negative charge here because of the uniform distribution symmetrical distribution this also have the core of the atom; where there is a positive charge. So, there is a net distance of a separation. So, there is a no dipole moment generated although there is a positive charge and negative charge but d is 0.

So, when you are talking about q into d; d is zero therefore, there is no polarization. So, it is a unpolarized situation unpolarized situation of the atom but when we apply a electric field this is the direction of the field there is a separation. That means, the electron cloud is no longer spherically symmetric but it become ellipsoidal. Once becomes a ellipsoidal the centre of negative charge is here and the positive charge is here and therefore, there is a net distance of separation. And, so just by applying electric field there is a redistribution of the charge and therefore we will get a dipole moment; and the particular atom gets polarized. So, that is happening in the atomic level with in each atom each of these atom will have a electronic polarizations. Sets in when an electric field is applied.

Next is atomic polarization. Now, in this case we are talking about 2 different atoms not electrons these are 2 different atoms. There is a bond chemical bond between this atom and this atom, this spring represents some kind of bond. So, they are not free they are not completely free they have some kind of binding energy or binding force and that spring represents that. So, initially this is the distance of separation unlike here the distance of separation 0, here there is a distance of separation because one cation. For example, one cation is located next to an one anion, but there is a distance of separation or inter atomic spacing.

So, these are actually inter atomic spacing which is shown here and this spring is represents some kind of bond or some kind of binding force between the 2. So, there is a if you are just considering this set of negative and positive ion there is a polarization. However when we are talking about the whole solid these moments will cancel each other because they are distributed in the random passion; and there is a not only random and there is systematic fashion. So, that the overall dielectric moment or dipole moment is 0. So, one is positive, one is directed in this direction may be the next one will be directed in opposite direction.

As a result the whole solid will have a net 0 dielectric moment or dipole moment. However when we apply electric field just like here there the spring is elongated or extended. So, the distance of separation between these 2 and the distance of separation between these 2 in this condition is not same; these may be a little higher than this. So, as a result the there will be again a net dipole moment. So, there will be increase in dipole moment in this situation compared to that situation. So, that is also give rise to polarization. So, this is a atomic polarization or sometimes also called ionic polarization.

Because if there are ions actually it happens between the ions this is one this is anion and this is cation. So, it is more of an ionic polarization.

But, it is taking place in the atomic level of atom atomic level. Then there is another third kind of polarization what we call a orientation polarization. This is very special case in some materials not in all materials. In some of the materials there is already a dipole moment present we will see a group of material called ferroelectric materials where just like ferromagnetic materials. Ferro magnetic materials you have magnetic dipoles here in ferroelectric materials we have a electric dipoles already present because of certain crystallographic consideration or crystallographic nature of that particular structure. So, in such cases you have just like a ferromagnetic material.

You have a dipole moments present already some dipole moment are already present, but they are randomly distributed. Here they are in a random fashion directed in different directions and therefore, the net dipole moment of the overall solid is 0 here. However when we apply a electric field they try to align themselves because they have a dipole moment, they have a particular direction they want to remain; and if you apply an electric field from outside. They actually try to align themselves along the field is along the field directions may not all of them may not completely align may not come parallel to each other. But depending on the applied electric field they will tend to come parallel to the electric field. So, consequently there will be change in the overall dipole moment.

So, this from a 0 dipole moment situation because of the randomness because of the randomness you have 0 dipole moment overall dipole moment of this solid is 0. Whereas, in this case because of the realignment there will be a net dipole moment. So, that is also another way the material can get polarized or respond to an applied electric field. So, this is third kind of that is why because it involves only a orientation reorientation of the dipole moment it is called orientation polarization. The fourth one the last 1 is space charge polarization this is very similar to an electrochemical system the polarization. which happens in an electrochemical system.

Electrochemical system we have electrolyte and electrode and there is an interface. So, in any electrochemical system there is the charged transport through the electrolyte and then the charge gets neutralized at the interface of the electrode, electrolyte interface. So, and if this interfacial reaction is not fast enough compared to the volume moment of the charge within the electrolyte. Then there may be a charge accumulation at the surface, at the impact ,at the interface of the electrolyte electrode electrolyte interface.

In fact we have seen that here also more or less when you are talking about a capacitor the parallel place capacitors which we have discussed earlier. It is basically analogs to an electrochemical system; where the electrolyte is dielectric and the electrode is the parallel conductor plates. So, there may be accumulation because the there is small range, small length or short range moment of the ions. So, there may be a rearrangement of ions at the interface. If this may be the interface this is one here you can see both negative and positively charges are distributed more or less randomly.

So, there is no net accumulation of charge are net dipole moment is 0 once again in this case. Because of the short range orders or sometimes there may be a long range order or not short range moment. You can see here after the application of the electric field in the negative charges goes towards right and the positive charges tends to go towards the left. And, because of the interface there they are not getting fully neutralized with the electrodes placed here. And, therefore, more number of positive charge gets accumulated on this surface, and more number of negative charges gets accumulated on another surface.

So, instead of a complete random distribution you have a preferred distribution. On one side the positive charges moves in one direction and the negative charge moves in the other direction. And, they gets accumulated on the surface or the interface and that also give rise to a total or increase in dipole moment and therefore, a polarization. So, this is the last kind of polarization mechanisms. So, you have 4 different kind of mechanisms by which the material can get polarized or creation of dipoles moments or increase in dipole moment. That is what can happen? Impact there is another in the continuation with these mechanisms.

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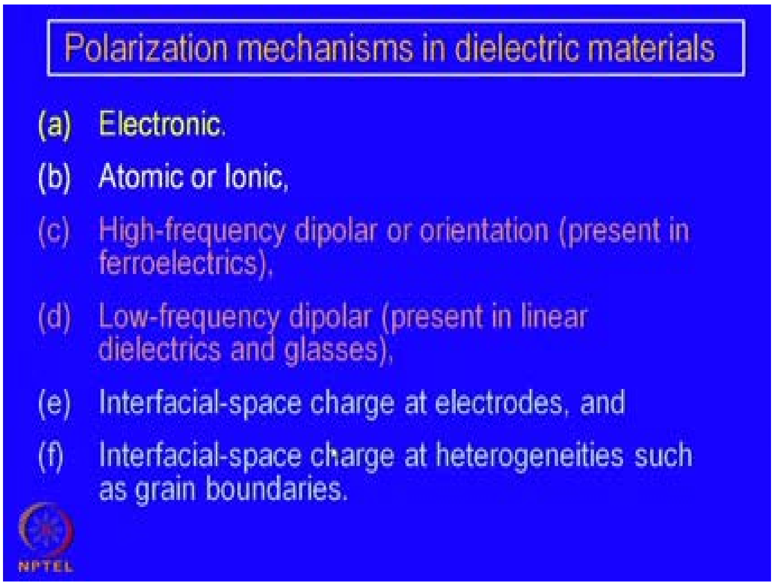

Here these four has been subdivided into actually 6. Well we have once again these are mechanisms; the electronic mechanisms does not have any sub classifications, atomic or ionic that also do not have a any sub classification or the other 2 this is orientation polarization and the interfacial polarization has two different sub subgroups. 1 is high frequency and is low frequency. So, high frequency dipolar or orientation present in normally ferroelectrics as I mention earlier and low frequency dipolar present in linear dielectrics or sometimes in glasses. So, there is a sub classification of this orientation polarization. So, in both these cases there is already permanent dipole moments present but there is different nature. And, so there is a sub classification here.

So, these 2 are actually 2 subgroups of orientation polarization. And, similarly the last one the space charge polarization also have 2 different subgroups. One is called interfacial space charge at electrodes as I mentioned and interfacial space charge at heterogeneities such as grain boundaries. Well have I mentioned just now that it is an normally a electrode electrolyte interface acts as a accumulation centre or accumulation site for the charge carriers or the charges but if there is a in homogeneities. For example, a grain bound in a polycrystalline material particularly in ceramics. We have an grain boundaries which is in homogeneities and that also creates a some kind of a surface.

So, when charges are moving across trying to move across the grain boundaries there may be a accumulation because of the imperfections of the lattice. So, in addition to the metal interface or the metal electrodes interface with the insulators or with the dielectric. Within the dielectric itself there may be some in homogeneities and that may also act as a site for accumulation of charges where the charges are not properly neutralized. And, therefore, they will be a accumulation and that accumulation will lead to the enhancement in the dielectric moment or generation of dipoles and dipole moment. So, that is also a centre where polarization can takes place. So, this is the polarization mechanisms. And, I think you can complete it here today.

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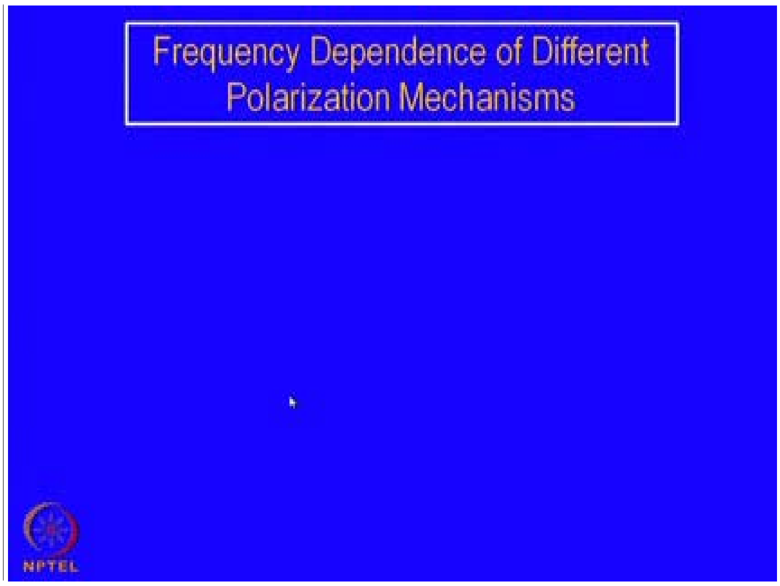

The frequency dependence of different polarization mechanisms I think we will take it up in the next lecture.

Thank you so much.