Solid State Physics
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Lecture - 72
Dielectric Property of Solid

So, today we will study Dielectric properties of solid.

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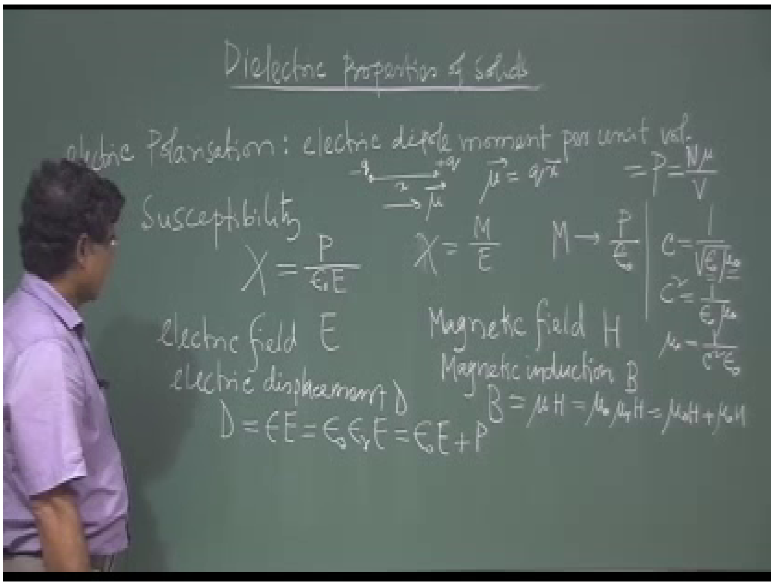

So, Dielectric properties and this magnetic properties of solid. So, these are very they similarity is a symmetry between these two properties. So, in case of magnetic properties that is the basically, response of the magnetic material in terms of magnetic field, whereas, this dielectric properties that is response of this material to the electric field. So, you will see that both a very similar. So, I will teach these properties very briefly. So, this that polarization similar to magnetization. So, magnetic polarization electric polarization are in case of magnetic polarization this we tell magnetization in case of electric polarization. So, you simply tell polarization.

So, polarization is defined as the electric dipole moment, like magnetic dipole moment per unit volume, electric dipole moment per unit, volume per unit, volume right. What is electric dipole moment? So, this negative charge equal amount of negative charge and positive charge. If they are separate by distance X, then electric dipole moment say if I write same MU. So, here MU is electric dipole moment, this basically QX and it is direction, is direction is basically, from negative charge to positive charge. So, this dipole moment, electric dipole moment, direction is this. So, this then similar to the magnetic property, say another parameter here also the same susceptibility. It is CHI electric susceptibility. It is CHI. CHIIS like magnetization by this magnetic field. Similarly, here polarization P. If I write this one is polarization, this polarization P equal to, if N number of dipoles per unit volume.

So, and each dipole is having this moment is MU. So, let the N MU will be the N MU will be the polarization. Since N, we have taken as a number of dipoles per unit volume. If I take this in general, this capital N is the number of dipoles in volume V. So, then one can write N MU by V. So, here this polarization divided by electric field. So, this epsilon E. So, here this epsilon that is a permitivity in vacuum in year. So, we just here this comes, because of this SI unit. So, earlier whatever, we have seen this in case of magnetic property, they are just magnetization by E magnetization by E. So, if you. So, in this case thus, just you can see this, if M is replaced by P by epsilon 0 then you will get this relation. So, this why this epsilon 0 has come that is one can as you know this, you know velocity of light, is you know the square root of square root of epsilon 0 MU 0.

So, you can check it if you know the value of, with the standard this constant you can get this value from book. If you put these 2 value then it is a, it will give you velocity of light. So, C square equal to one1by epsilon 0 MU 0. So, this in electrical magnetic here, you can see this C square is constant right velocity of light in year in vacuum. So, basically, MU 0. Wherever MU 0, in this other cases, it will be MU 0, then it is C square epsilon 0 . So, this inverse relation with MU 0 and epsilon 0. So, that is the reason in SI unit this comes at the denominator. So, that the susceptibility that is the another parameter to describe the dielectric properties of solid and then electric field like magnetic field, electric field that is E and magnetic field, Similar in case of that is magnetic field, H right so.

So, here we have seen this magnetic induction or magnetic flux, density magnetic induction of flux density that is B. Similarly, in this case also you have this it is called electric in this case. It is called electric displacement, is D. So, this in analogy, it is similar to B. So, electric displacement. So, B, you have seen this B equal to MU H. So, MU was the this a permeability right and then MU 0 MU 0 MU R H. Similarly, here this

D is basically, permitivity epsilon then E epsilon E. So, this epsilon E is epsilon 0 epsilon R, just same way this the relative permitivity, yes E right and this equal to this equal to epsilon 0 E, that is the applied 1 applied electric field epsilon 0 E plus polarization P. So, in this case you remember, it was MU 0 H plus MU 0 M right. So, here MU 0 is there as I told this, because of this relation.

So, MU 0 is there. So, now, here that epsilon. Suppose, to be epsilon, but this inverse relation. So, that is the. So, this P. So, this the; so, here from here. So, CHI equal to P by epsilon 0 E right. So, from here, you can see from here that P equal to I can get P equal to epsilon 0 E epsilon R minus 1 epsilon R minus 1 right, same things in case of magnetic. So, CHI is basically, from here that P by epsilon 0 E equal to epsilon R minus 1. So, this will CHI, here epsilon R minus 1 right. So, these are the standard parameters for dielectric properties. What is this polarization, susceptibility, then this permitivity, this relation are same as we have seen for the magnetic properties. So, now. So, we have defined this parameters to describe the dielectric properties of solid. So, let us see the property, how properties varies with how properties varies with the, with electric field and temperature right. As we have seen in case of magnetic property.

So, here there is a basic one difference between this electric field and magnetic field, you know see electric field is produced by you know this magnetic field is produced by this solenoid.

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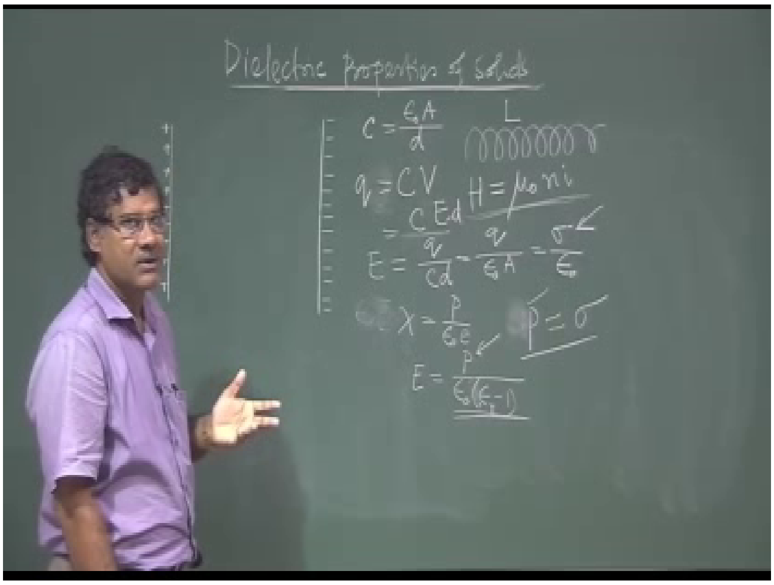

Solenoid long, solenoid if you take this magnetic field H or B whatever. So, that is MU 0 N I current flowing through this, then at the center inside, this solenoid. So, this and this N is number of transfer unit length, number of transfer unit length. So, that is the gives magnetic field. So, these the solenoid. We use in our laboratory to produce magnetic field. Similarly, to produce electric field, we use condenser capacitor. So, this is called inductance. In this case of case this, there is induct inductance and in this case condenser capacitor C, capacitance C and C, you know this one can find out epsilon 0 A by D; D is distance between these two plates.

Now, if you apply voltage between these two then there will be charge, there will be charge accumulation on these two plates. This basically, metal plate, these are metal plate. See if you apply voltage V, if we apply voltage, just connect battery. So, it will be charged. So, relation how much charge will be accumulated, how much charge will be hold by this 2 plates. So, P equal to C. So, Q is proportional to V voltage, what a voltage you will apply. So, amount of charge will be. So, in this case charge whatever, the function of charge. So, other case is a function of I. So, this V is basically, C electric field by not by into D right into D.

So, electric field one can write Q by CD right Q by CD that is the capacitor Q by CD and Q by CD, if C, if you replace C Q charge by epsilon 0. So, DD will go. So, basically epsilon 0 A right. So, here is very important, you see this charge on this plate right. So, this and this area of this plate. So, this I can write, charge density, surface density, charge surface density on this, on this plate that is sigma by epsilon 0. So, electric field is basically, the charge density on the plate, on the surface by this epsilon 0. So, this very important relation and later on and later on I can show, you in principle what I wrote E epsilon 0 E that CHI, you have CHI equal to, you wrote P by epsilon 0 E right epsilon 0 E, right.

So, see if I. So, electric field yes. So, here what I want to show that one to tell you that basically, this surface charge density and this polarization, they are probably here I can show directly P equal to this again E equal to yes I think epsilon 0 E or I can write from here I can write E equal to P by epsilon 0 I CHI is susceptibility and. So, from these two form and CHI is CHI is nothing, but what was that epsilon CHI was epsilon R minus 1 R minus one kind of things right. So, this P from here, you can see E equal to this sigma by this epsilon 0. Now, in case of here, is it I just, what I wrote this epsilon R equal to CHI equal to epsilon my R minus 1 that is true in case of here, CHI 0 that is true. So, this the basically, related with the permittivity, yes in this case is this. So, in case of.

So, here this P and this surface charge. They are related and generally we tell that this P is equal to this P is equal to it is a surface is equal to the surface charge density on the surface. So, electric field is related with the surface charge density and this polarization also, it is related with the surface charge density. So, in terms of either in terms of surface charge density or in terms of Q as P. I have shown in that the dipole moment per unit volume. So, dipole moment is nothing, but the charge into the separation of them, charge into the separation of them. So, that is thus, this electric field and polarization it is related with the charge and again here, just I try to tell you that they are related with the surface trans charge density in whether in terms of surface charge density or in terms of charge, we can express them.

So, here just what I want to show you that if I take two capacitor plate. It will produce electric field and this field direction is you see, it is the, this direction electric field direction if I write this is a E 0.

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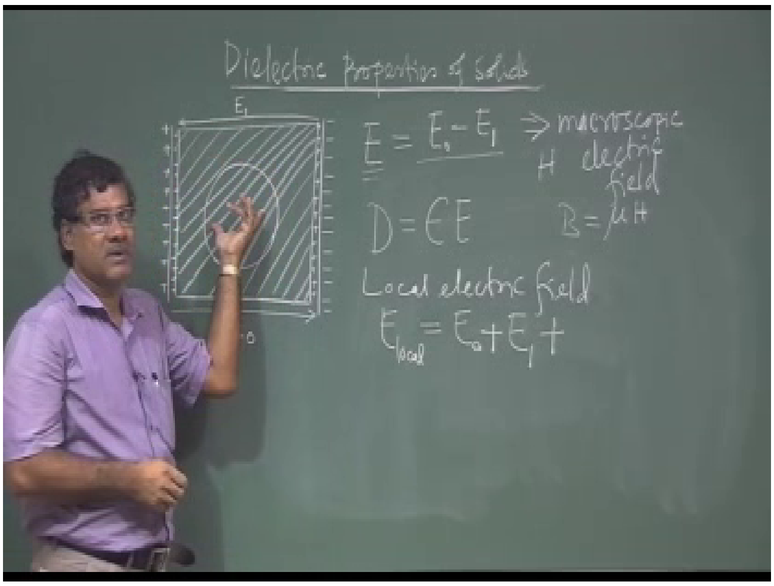

So, inside that is the dielectric material. So, then electric field generated by this two metal capacitor plate is this E 0. Now, if I put dielectric inside, this say one slab of dielectric material inside this capacitor plate. So, these are dielectric material. So, then what happens, then immediately if it is dielectric material, immediately that is on the surface of the dielectric. So, there is a induced charge, I can think that there will be induced charge. So, what happens this effective charge will decrease their whatever the charge here. So, that charge, amount of charge, effective charge will reduce will decrease.

So, this. So, as if a here, now you see this negative charge and positive charge. So, this basically, this because of the polarization of this metal. When it is put in this electric field, they will be polarized, there will be induced polarization and that because of that polarization. So, this and this positive charge. So, this polarized by polarized of atoms or molecules are dipoles. So, they are negative side, it will be attracted this side, positive side will be attracted this side. So, thus it is the, we tell this positive one is induced, negative charge on the surface of the dielectric and this negative charge, induced positive charge on this surface of the dielectric without considering any from any atomic view of point. So, just we can see this one and then here, you can see this electric field for this charge. So, this direction will be this direction right and this say if we write E 1, this one due to the polarization.

So, polarization of this dielectric material. So, this E 1 is this 1. So, here effective electric field, whatever this material will see or we tell macroscopic not microscopic, macroscopic electric field, that is we generally consider the external electric field, whenever we apply external electric field without any dielectric in vacuum. This is E 0, when dielectric materials are there and we apply this electric field. So, this materials will see the electric field that is E equal to basically, E 0 minus E 1 right. Yes, E 0 minus E 1 and. So, this call, this E is called basically, microscopic not microscopic, macroscopic electric field. So, thus. So, generally, we write this E that as a external applied electric field, when it is in vacuum.

So, this E 1 is 0, when it is in on a some material, dielectric material then this E 0 that is reduced by this one. So, electric field in material electric field in material, is less than the electric field in vacuum. So, this is just difference in case of magnetic field. It was different in that case, this in magnetic material, this electric magnetic field is enhanced but here it is decreased, but. So, their magnetic field is increased that we express in terms of B express in terms of B. So, this one, we are not expressing in terms of just D, but this we have taken, this a resultant one, we have taken as a electric field. So, now, these defined. So, as if this material, we see material, we see this electric field, it will take that externally, this electric field applied. Now, that we have taken as a electric field, external electric field, which is similar to, still it is similar to H. So, B compared to B. So, that is D, is defined as a now, this electric field D. We have defined as a EPS epsilon E, right.

So, this E is not E 0 in vacuum. It will be 0, because this will be 0, this effect will not be there. So, this is electric field, it is not electric displacement, similar to this is defined, now this D similar to B. So, this will be defined MU H. So, macroscopic electric field is basically, this E not E 0, material will see this electric field. So, that is equivalent to the, whatever the way, we define this magnetic field. So, that is important difference between this two and then now, then what we would like to see. So, that is macroscopic electric field as a whole. This material will fill this electra way electric field E. Now, what is the field atom will see. So, in point of MA microscopic point of view, from microscopic point of view, what say at here 1 atom is there, when this field E is applied.

So, this material will see this field E. So, whether this atom at the center, here or anywhere, whether it will see the same electric field or that field will be different. So, that field will be different. It will not see this field, that is called the local electric field, which atom or molecules in the material sees. So, that is if I write E local, locally what is the field that atom will see. So, that is defined from this field. So, that has that continuation will come in this field. So, 1 is E 0 from this whatever field that, it will see then whatever field from this surface charge of the dielectric. So, that it will see then what it will see, it will see this whatever the polarization or dipole moments are surrounding, either it is induced dipole moment or permanent dipole moment whatever.

So, because of this, it will feel some, it will, it will see some field. So, that. So, that Lorentz. Basically, calculated this local electric field. So, he find out the process how to calculate. So, what he has done. So, here it is taken a sphere it is taken a sphere radius of sphere. Sphere is greater than the dimension of the dipole dimension of the dipole. So, now, it is. So, Lorentz calculated this one that he told that here. So, because of this dipole surrounding this whole dipoles. So, there will be effect on this it will give electric field on this.

So, if you just make a cavity inside this, dielectric material right. So, make a cavity inside the. So, take out this dielectric material from here.

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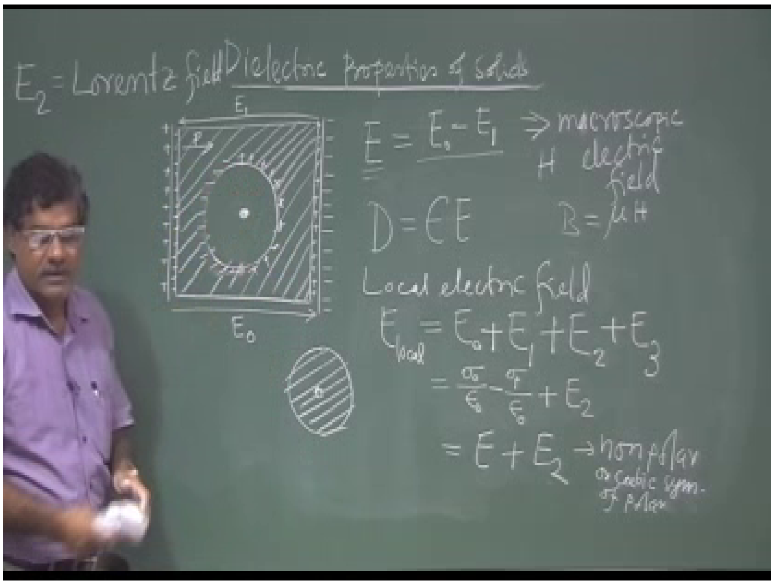

So, at the center of this sphere, this 1 atom, it will see the electric field, because of the surface charge on this sphere surface, charge on this sphere. So, surface charge on this sphere, because it is already polarized due to this external electric field. So, it will polarize like this and this other side negative, other side negative no, because polarization is in this direction. So, I think this, I have to put here. So, polarization direction of polarization is basically, negative to positive.

So, here. So, direction of polarization, for this electric field is this direction for positively, that is the polarization direction. So, here polarized in same way. So, this will be negative and this will be positive. This will be positive. So, this will see the dipole moment or polarization or that is equivalent to the surface density, charge density on this surface. So, this. So, it will produce electric field at the center that if it is that is E 3, sorry E 2 then E 2 is the electric field produced by this surface cavity by this, surface of the sphere inside, surface of the sphere that is. So, now, this material we have taken out, but material is there in principle. So, now, I have the surrounding this. So, this material is there. So, dipole moments are there, if it is polar material, means if it has the permanent dipole moment. So, due to that dipole moment, see it will see the, also this will contribute the electric field at the center.

So, material inside this cavity whatever was there. So, because of that, it will feel electric field center. So, that if it is E 3. So, this local electric field will have this 4 contribution.

So, these are this, E 0 is this one that is the standard one, this basically, surface density on this I can write E 0 on this external plate and that is why epsilon 0 electric field, epsilon 0 right and this 1 E, 1 is basically surface density on this, if I write it is the due, 2 polarization sigma P surface density. So, this will be epsilon 0 and this negative sign and now, E 2 we have to calculate. So, E 2, we have to calculate and then E 3, you see this E 3, if it is non polar material. So, E 3 is 0, because this here, because of dipole moment inside this PA permanent dipole moment, only it will see the electric field. So, this E 3 will be 0 or in case of dipole moment also, if depending on the structure of this, material depending on the structure of this material.

So, this field can be 0 also. So, one can show this calculation, but I will not go in to details. So, here it will see this, electric field 0, because of this if it is non-polar dielectric, even if it is polar dielectric, if this, if cubic symmetry is there, this material have cubic symmetry. Then also one can show this E 3 will be 0. So, if it is not cubic symmetry other. So, in general E 3 may not be 0, but non dipolar case or in case of polar, but there is a symmetry. Let us say the cubic symmetry. So, E 3 is 0. So, let us do for the either considering, the cubic symmetry for polar case or thus non-polar magnetic material. So, E 3 is 0.

So, E 3 is basically 0. So, this. So, then local field here, it will be this. So, this we write generally, this is E macroscopic electric field and then your local field E 2. So, E is there, whatever just we tell, we use this electric field as a field, which this as a whole this material see and then additional field atom will see, that is E 2 in case of polar material, non-polar materials, or cubic symmetry of polar material. So, now, our task is to calculate this E 2 and this call E 2 is called the Lorentz field. So, that so. So, now, I have to calculate only this one. So, then I think, I will calculate in next class. So, let me stop here.

Thank you.