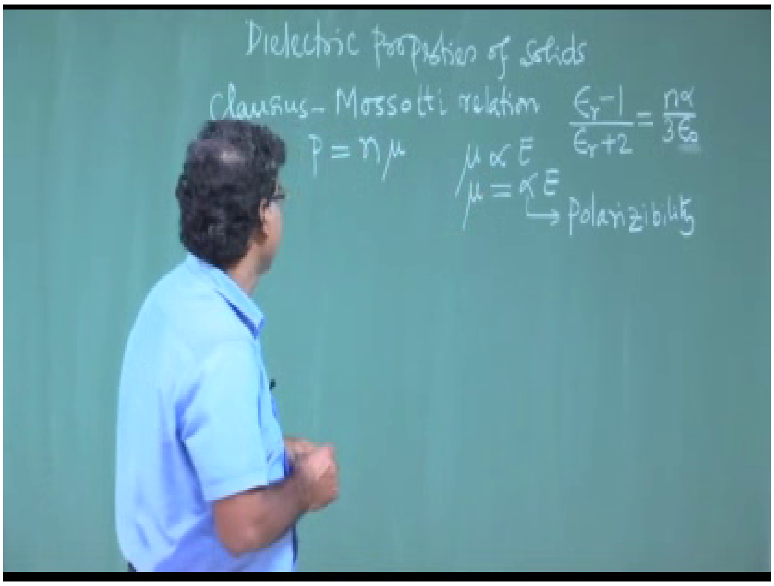
Solid State Physics
Prof. Amal Kumar Das
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture - 74
Dielectric Property of Solid (Contd.)

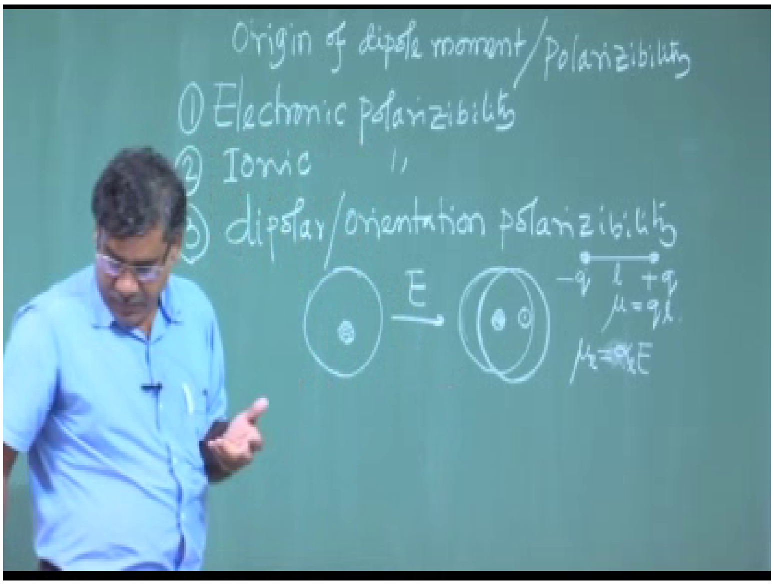
(Refer Slide Time: 00:24)



So, we will continue our discussion on dielectric properties of solid. So, we have derived the relation, Clausius Mossotti relation; that is epsilon r minus 1 by epsilon r plus 2 equal to n alpha by 3 epsilon 0 right. So, epsilon r, the dielectric constant or relative permittivity and epsilon 0; that is for dielectric constant for year or back worm, say its absolute permittivity epsilon 0, is basically absolute permittivity, and epsilon r is the relative permittivity and n is the number of atoms or molecules per unit volume; that is basically number of dipole moments per unit volume. No that is the number of atoms or molecules. So, if each molecule or atom having the magnetic moment mu.

So, then n into mu that will be the polarization. So, p will be equal to n mu is the dipole moment right and alpha is the polarizability. So, that is defined that dipole moment per unit electric field. So, basically dipole moment for a atom or ion or molecule; that is proportional to electric field and that proportionality constant is alpha, and this alpha is called polarizability, right. So, that is what we have discussed in earlier class. So, now, this today I will discuss what is the origin of polarizability or the dipole moment, or the polarization in dielectric material.

Refer Slide Time: 04:31)



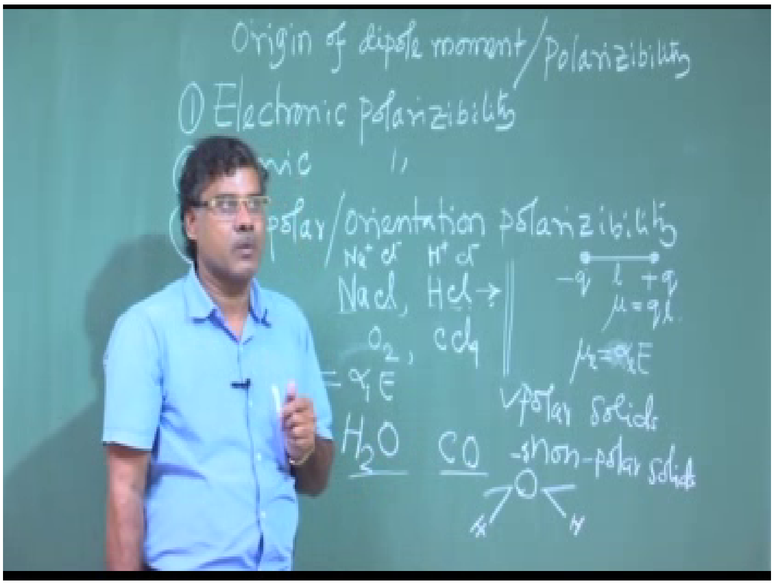
So, we will try to find out the origin of polarization or dipole moment, and then dipole moment or polarizability in dielectric material.

So, in case of magnetic metal that we have seen, the origin of magnetic dipole moment was the induced dipole moment, as well as the angular momentum, dipole moment due to angular momentum. So, they are; this orbital angular momentum, spin angular momentum as well as nucleus nuclear angular momentum. So, that was the origin of the magnetic dipole moment. So, here in case of dielectric material; so, there are three types of dipole moment or polarizability in. So, one is called electronic polarizability, then electronic polarizability means, from there basically you will get dipole moment as well as the polarization. Second is ionic polarizability, third is dipolar or orientational polarizability.

So, electronic polarizability. So, basically distribution of electronic charge in atom; that is the source of electronic polarizability. So, in atom there is a nucleus, and the charge is distributed charge is distributed surrounding of this nucleus. So, in the atom centre of gravity of this electronic charge distribution, and centre of gravity of the nucleus, they coincide. So, as a atom is neutral, as a atom it is neutral. So, when you apply electric field, then basically what happens, electric field, it applies force on positive charge and on negative charge in opposite direction. So, thus this; so, originally say. So, this is the nucleus. Now if you apply electric field. So, this centre of gravity, they will not coincide anymore, because negative charge and positive charge they feel force in opposite direction. So, then basically if you keep this nucleus at fixed position, then you can say that this electronic charge is displaced, if center of gravity of this electronic charge is, say this one.

So, this one, the positive plus z e charge, and this will be the negative minus ze charge. So, then it will form dipole moment, because dipole moment you know; that is minus charge, say q and plus charge a q plus q. So, they are separated by distance say l. So, then dipole moment mu is basically ql. So, here. So, there is a equal amount of charge, now they are separated. So, it will form dipole moment. So, this dipole moment mu is electronic dipole moment, its mu, say mu. So, will write mu e to differentiate this different kinds of dipole moment. So, electronic dipole moment. So, mu e is proportional to e, and this proportionality constant here, we write alpha, alpha e, alpha e is the electronic polarizability. So, source of this polarizability is basically the electronic charge of the atom. So, it is for in case of neutral atom, this dipole moment is formed and second case is a ionic dipole moment, ionic polarizability. So, that is seen for the ions basically, say for the ion, say sodium chloride Hcl, Hcl molecule, then oxygen, then yeah ccl 4.

(Refer Slide Time: 11:09)



So, they are in ionic formation and in this. Sorry yes. So, this sodium chloride, they are basically is in molecule. So, they are in ionic form sodium ion and chlorine ion right Hcl

H plus cl minus right, and oxygen also. They have ionic form, means it is not in molecule, it is not neutral. So, this they shows this ionic dipole moment. So, here basically they have in ion form, they are in ion form, and when we apply electric field then positive ion and negative ion, they will be just separated, because they feel the opposite force due to electric field. So, this all ionic, ion basically ionic. So, all ions basically they are; one is positive and another is negative. So, before applying electric field, there is no dipole moment. If there is no dipole moment, then after applying electric field. So, this positive ion negative ion, they will be displaced in opposite direction.

So, this also, there will be, then in that molecule due to this displacement of ions, you will get the dipole moment. So, this is also induced dipole moment, because it is induced by the electric field. So, you will get dipole moment mu, and this if you write mu I; that is ionic dipole moment, it is again equal to alpha polarizability, ionic polarizability alpha i e, right. So, now, as I mentioned that this ionic polarizability or polarization or dipole moment. We see in case of ionic ions in molecules ions are there, both types of ions are there.

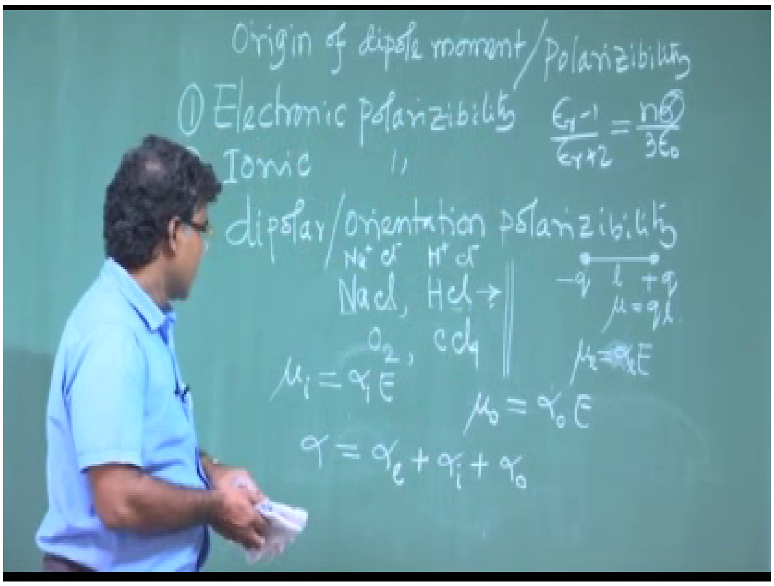
So, before applying electric field, this molecules having ions, they may have dipole moment, they may not have dipole moment. So, whatever the case, whether dipole moment originally dipole moment is there or not, but after applying electric field. So, will get this induced ionic dipole moment. So, when this before applying magnetic field, if this molecules are having dipole moment, then that is basically called permanent dipole moment, and that material is called polar material, polar dielectrics, polar material, polar solids or dielectrics.

Whatever if they do not have permanent dipole moment ,then it is called nonpolar dipole moment, nonpolar dipolar moment, nonpolar solids nonpolar solids. So, this electronic polarization or polarizability ionic polarizability; that is common for polar solids and nonpolar solids. So, this third one dipolar or orientation polarizability that is for only solids which are polar, means they have permanent dipole moment, they have permanent dipole moment, like you know this water H 2 o water is polar material, this carbon monoxide is polar material, yes.

So, in case of water, you know this in case of water, this bonding, they, its not, bonding is not like this, there is angle. So, then minus some delta amount of charge, and in case of hydrogen, then delta plus delta amount of charge. So, they are separated with some distance. So, then we tell that, they have permanent dipole moment carbon monoxide also have permanent dipole moment, but carbon dioxide do not have this permanent dipole moment, because it is their bonding is, I think bonding is, there is no angle. So, they do not form permanent dipole moment. So, bonding is basically, put this way anyway. So, the materials which are having permanent dipole moment. So, that is material is called this polar material, polar dielectrics, polar solids. Now their dipole moment, permanent dipole moment mu, and now this dipole moments or randomly oriented in the material, or this, yes.

So, now if you apply electric field then what happens. See in this case also what happens this dipole moments, they will feel the torque due to electric field, because torque in case of magnetic field you have.

(Refer Slide Time: 18:56)

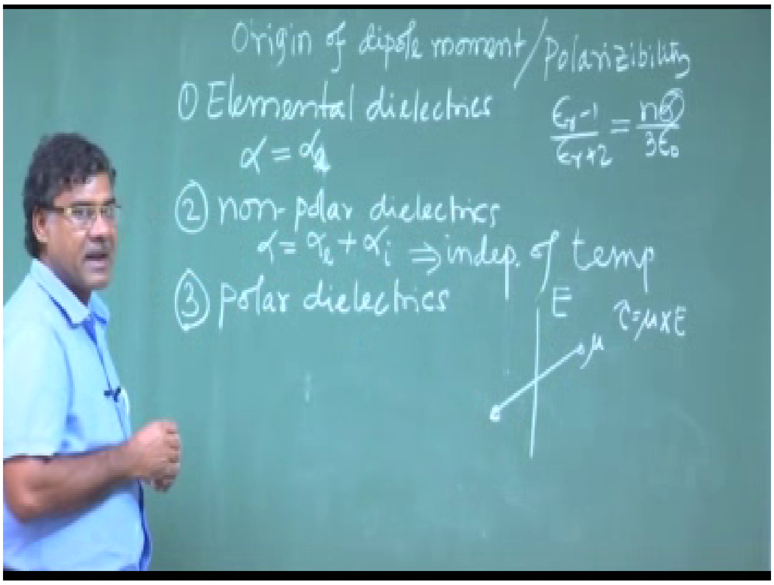


You have seen n cross h. See in this case, it is mu cross e electric field. So, they will feel torque, and they will try to align towards the electric field, they will try to orient towards the electric field. So, then you will get the net polarization or moment due to the orientation, along the electric field. So, that if I tell that dipole moment, is say due to orientation, it is mu 0. So, that will be equal to alpha 0 e. So, this alpha 0 is called the orientation, orientation polarizability or dipolar polarizability.

So, when will apply electric field, then this materials will, the source of this dipole moment are basically this 3 electronic ionic, and dipolar moment and as a whole you will get contribution from all source. We will get electronic contribution, ionic contribution, dipolar contribution, but that. So, total alpha polarizability of this atomic polarizability; that is basically alpha e and then ionic polarizability; that is alpha I, and then your alpha 0 alpha 0 . So, this will be the, this alpha will be the net polarizability for the atoms or ions or the molecules under electric field. So, this, that relation I wrote that relation, I wrote that Clausius Mossotti relation they are this n. So, you wrote n alpha n alpha. So, epsilon r minus 1 by epsilon r plus 2 equal to n alpha by 3 epsilon 0. So, this is alpha, whatever we are discussing. So, this, the alpha, now you see there are three contribution in this alpha, but it depends on the material, you know in some materials, there may be, may not contribution some of them, or one of them. So, that is why.

So, if we generally tell that in case of elemental material or dielectrics, elemental dielectrics in case of elemental dielectrics.

(Refer Slide Time: 22:46)



So, I think I can use this space. See in case of elemental dielectrics. So, they are your this alpha. So, this contribution only comes from this electronic contribution. So, in that case alpha is basically only alpha i. So, there will not be contribution. So, not alpha e. So, its because there is. No its elemental dielectrics. So, there is no ion. So, this contribution will not be there, and it is not, there is no permanent dipole moment. So, there will not be this orientation contribution. See in that case this alpha is basically alpha e. So, in non polar material. In case of non polar material, means permanent dipole moment is not there. So, another case can be nonpolar dipole, the electrics nonpolar dielectrics. So, in that case there is no permanent dipole moment. So, in that case contribution will be from alpha e and this alpha i. So, no contribution from the orientational polarization or polarizability.

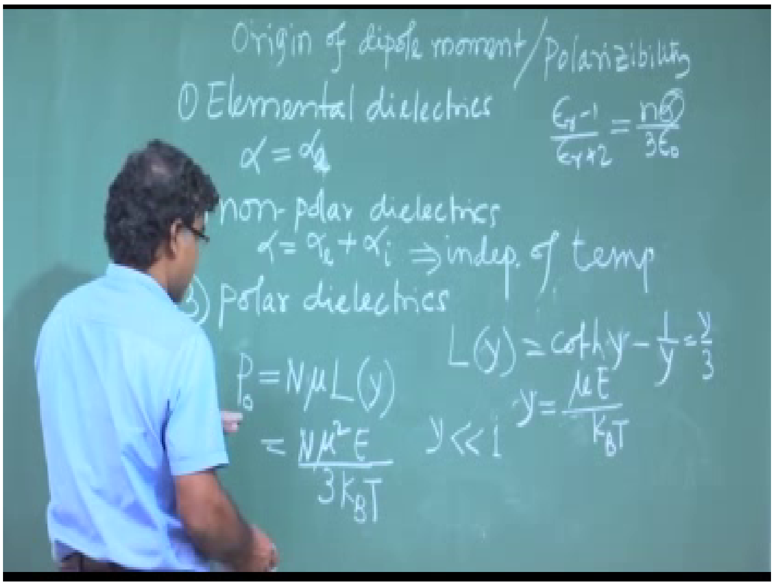
So, this alpha i and alpha e basically depends the structure of the atoms ions or molecules. So, that is why, its the independent of temperature, they are independent of temperature, but this alpha 0, alpha 0 orientational polarization, or dipolar polarization or polarizability. So, that depends on temperature, because this comes from the orientation of the dipoles along the electric field. So, if temperature is change in this solids. So, this thermal energy. So, that depending on that; see it will try to misalign or disorder this dipole moment, just reverse of that electric field will try to align them, and thermal energy will try to misalign them or disorder them. So, this polar material, third case is polar material or polar dielectrics, in case of polar dielectrics. So, this there will be contribution from all, this electronic ionic and as well as orientation polarizability. So, all thrre contribution with. So, in that case, in case of polar material.

So, this alpha basically have this, all three contribution. So, this now I will show that this alpha 0 is basically, is depends on temperature, and that we can show easily. Now you see, now imagine that you have dielectrics, you have materials, this materials is having the permanent dipole moment. So, this atoms or ions or molecules are having permanent dipole moment. Now just think about this paramagnetic material. So, there we use this term, this paramagnetic gas, means we considered, we assume that the magnetic dipole moment of each atom.

So, they, there is the interaction among them. So, they are free to rotate there, they are free to rotate their dipole moment. So, similar concept you can apply here also. So, you have now in place of magnetic dipole moment, you have electric dipole moment in place of magnetic field, you are applying electric field. So, along the electric field, if you apply electric field in this direction, it will have dipole if you have dipole. So, dipole will try to, with there will be torque, as I told that dipole, if you have dipole mu say.

So, then mu cross e. So, this is the torque, this, it will feel that torque can try to align along the electric field direction and. So, this now same way one can find out. There is the Langevin function you remember in case of paramagnetic gas; say in case of this polar dielectrics, which is having this permanent dipole moment. Now if you consider the way we derive this Langevin function for paramagnetic gas. So, just if you derive that same way, because some things there is no difference.

(Refer Slide Time: 29:38)



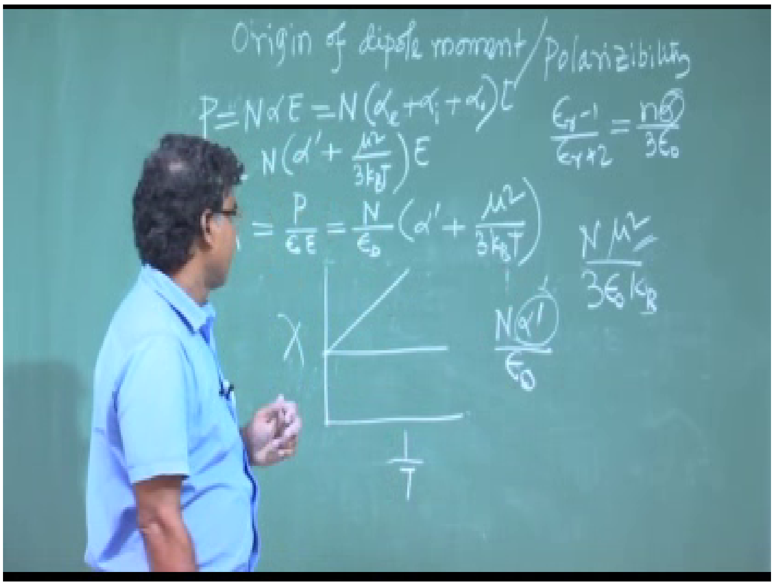
So, then that you will get Langevin function, and as we found that the polarization, basically polarization in that case magnetization in case of magnetic, in this case polarization due to orientations; so, I am writing p 0, this p 0 is basically n mu, and then Langevin function.

So, where l alpha is, what was that cot hyperbolic, it was cot alpha Langevin function. This was I think cot hyperbolic alpha minus 1 by alpha; that was the Langevin function right. So, in this case alpha was, what is there alpha was. You remember this mu h in this case it is e divided by 3 divide by KBT, right. Now there will be confusion if I use this alpha here, just I have written, because in case of magnetic material paramagnetic gas we use this alpha. So, now, in this case for polarizability we are using alpha. So, let me write here just y in place of alpha, just let me write y here Langevin function y. So, let me write y, and for when alpha is very less than. So, not alpha here, I will write y, y is very less than 1; that means, higher t at higher temperature t here lower electric field. So, we have shown this Langevin function, this becomes alpha by 3 means y by 3 right. So, y by

3.

So, y is mu k mu e by KBT. So, this solution here, this p 0 we can write n mu, then mu e means mu square e divide by 3 alpha by 3 y by 3. So, 3 KBT same expression as we get that for the paramagnetic material paramagnetic phase. So, here this. So, this polarization just I do not need this one anymore.

(Refer Slide Time: 32:38)



So, here this polarization p 0 is basically; what is p 0, p 0 is n mu right, n mu dipole moment per unit volume. So, now, mu is basically alpha o e right, polarizability. So, if you compare these 2, then your alpha is, you are getting alpha o, is basically mu square by 3 KBT. So, as I told this alpha e and alpha i; that is independent of temperature I have not shown you, but just it depends on structure of the atoms molecules.

So, that is why one can think that this structure of atom or molecules say are does not change with the temperature. So, that is why, they are also independent of temperature and, but this orientation polarization, it depends on temperature this a, this the expression for this. So, basically your alpha in case of polar dielectrics. So, alpha is alpha 0 alpha e plus alpha I that is independent of temperature. So, I can write just alpha dash alpha dash for this 2 plus alpha 0 alpha 0 alpha 0 is mu square by 3 kbt. So, it depends on this type of materials, and that decides depending on that it is decided that this, which contribution will be there in dipole moment or in polarization. So, this chi is. So, chi one can see this chi polarization you know. So, chi I can I think you just chi 1, can write this yes. So, total polarization total polarization of this polar dielectrics, I can write, I think we are interested for polar dielectrics for polar dielectrics. So, total polarization as I told this all types of polarizability will be there.

So, this polarization n then n alpha e right. So, then n alpha e basically n alpha alpha e plus alpha I plus alpha 0 alpha 0, and that is I can write n and e, I have to write e sorry, yes e will be there. So, this basically n, then alpha dash I will write this independent of temperature one part, and this temperature dependent part is this mu square by 3 KBT. Now this chi is defined, chi susceptibility is defined is basically p by epsilon 0 e p by epsilon 0 e right, and that is equal to, that is equal to p is this, and e is there. So, then I will get basically n by epsilon 0, e will go and I will get alpha dash plus mu square by 3 KBT.

So, if I plot chi versus 1 by t 1 by t chi versus 1 by t. So, what I will get. So, in case of non polar material. So, this contribution is a, it will be independent of temperature. So, I should get this type of curve right, because this part will not be there. So, anyway if you do experiment on a dielectric material, and if you get the curve like this. So, then you can conclude that, this material is nonpolar material, if you get to the curve like this, then you will tell that this is a polar material and it varies because 1 by t, right.

So, you will get this, this will be the slope this into this n epsilon 0, slope will be n mu square by 3 epsilon 0 kb slope of this, and this intersection here, this n alpha dash by epsilon 0. So, then you can tell this is the polar dielectrics, and from the slope one can find out in principle, one can find out this dipole moment, and this from intersection, one can find out this. this this polarizability, which is independent of temperature. So, I think that is the things one can find out from the study of the dielectric material, and from experiment one can tell whether it is polar material or whether it is dipolar material. So, I think I will stop here, then I will continue in next class.

Thank you.