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

Lecture - 60
Magnetic Property of Solid (Contd.)

So, we will continue Magnetic Property of Solids.

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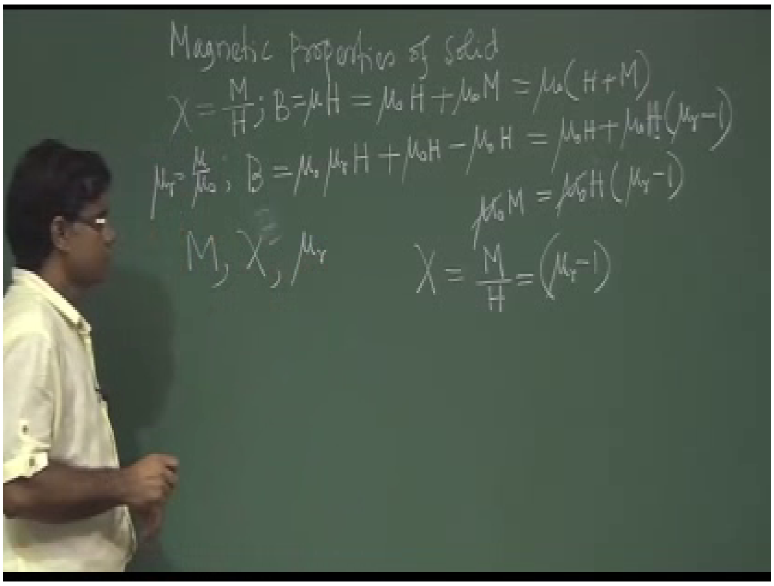

So, we have seen that to describe magnetic property of a solid we need some parameter. So, this susceptibility that is the magnetization by magnetic field right, and then permeability mu which is related with the magnetic induction B equal to mu h, see if we apply magnetic field on a material, then it is lines of force per unit area that increase. So, that is the magnetic induction.

So, it has 2 contribution basically one is mu 0; so this mu 0 H plus mu 0 M right. So, together it gives mu 0 H plus M. So, this M so that is also give magnetic field. So, that comes from material right. And this chi can be related with this with this refractive index, permeability of this magnetic material. So, this B equal to basically we write mu 0 mu r. So, mu r is this mu and mu zero, these are absolute permeability, this is for your (Refer Time: 02:59) nonmagnetic material and this mu is absolute value for a material magnetic material.

So, this mu r is defined by basically mu by mu0. So, this one can write this so higher mu r relative permeability, this mu by mu 0 basically right. And from there as I mentioned earlier, this plus mu 0 H minus mu 0 H if I just put here. So, from here one can write mu 0 H, and then plus mu 0 H mu r minus 1 right; so this from here mu 0 H and mu 0 M. So, this B equal to or this I can write in principle, from here itself I can tell. So, B equal to this also one can write right.

So, this will be equal to this. So, mu 0 will go. So, from here I will get mu 0 M equal to mu 0 H mu r minus 1. So, what I want? I want so mu 0, mu 0 you forget. I want chi equal to M by H, that will be mu r minus 1. So, thus this susceptibility is connected with the permeability. So, these are the magnetic parameter this M, then chi, then mu, basically mu r.

So, in terms of this we studied the property of the magnetic material right. So, that I have discussed. And further I have discussed that this is; what is the origin of this magnetism of a material. So, this so that I have I have discussed that material is made of atom they sits in a in the lattice site right. So, atom has again angular orbital momentum orbital motion.

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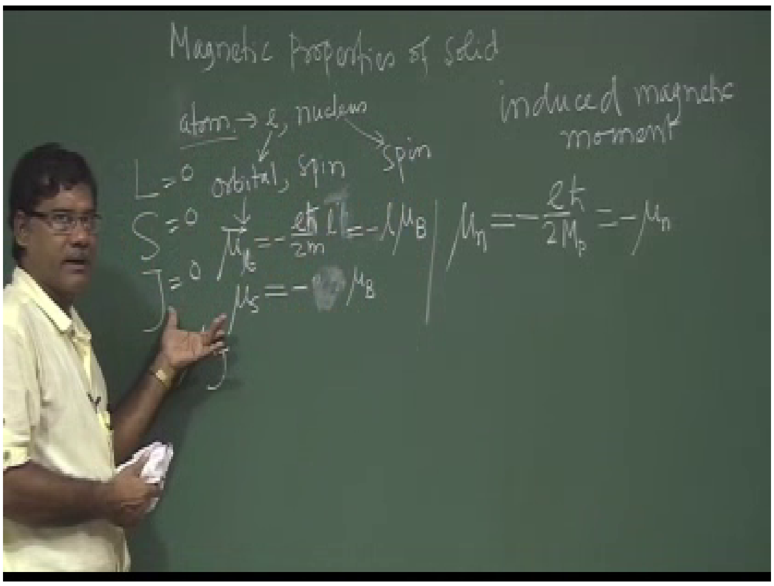

And then so atom have orbital motion electron atom, and there electrons are there outer shell electrons are there, and at the centre this nucleus are there nucleus right.

So, now these electrons have 2 kinds of motion, one is orbital motion, and another is spin motion, and nucleus have spinning motion spin motion so that we have seen this nucleus orbital motion, we have mu l that is minus e by 2 m into l h cross right. So, this h cross if you put here. So, it is gives basically minus l mu B. So, this l mu B, now here direction of these 2 basically in opposite direction; this we write these 2 are in opposite direction that is the indication of this negative sign.

And we get so when this l that is the quantized value l h cross, then we get minus l mu B. Similarly, for spin motion we get we get mu B minus g s s mu B for one electron. So, this is happened g is 2 as I mentioned. So, this will be one this 2 into half this one. So, minus mu B so apart from these 2, then we have mentioned that there is a mu n nuclear magnetic moment. So, that is also our spin. So, in this case minus e by 2 mp this mass is for this nuclear magneton, this is Bohr magneton. This is the nuclear magneton.

So, then your if I put h cross this we write minus mu n. So, whereas this mu and this is photon mass, this is heavier than the electron mass. And one can see that this mus and this mu n, this mu s is almost this is higher 10 to the 3 times of mu n. So, these are very small magnitude, and that we neglect this part when we consider this mu s mu l compared to these value these are very negligible value. So, that is why we sometimes we neglect. So now, atoms have many electrons means there are many orbits, and these electrons have spinning motion.

So, that total angular momentum one can calculate capital L, capital S right. And then the considered the ls coupling that is the j. So, that I have discuss about this, but further I will discuss whenever necessary. So, this is the so atom have this resultant magnetic moment, some magnetic moment considering this total angular momentum that is mu j. So, each atom has mu j value right; Mu j value magnetic moments. So, atom is attached with a dipole magnetic moment.

So, when these atoms are in solids. Now how these moments are oriented in the crystal in the solid with respect to some direction in space. So, that direction is in space is generally taken as the direction of the magnetic field. So, when we apply magnetic field on this system. So, these moments magnetic moments, they interact with this magnetic field, and they reorient and as a result we get the magnetic property in terms of magnetization chi or for permeability right. So, this so every material every atom in a material have the permanent dipole moment. So, this is the permanent dipole moment.

So, this is another kind of moment are there in in in atom when magnetic field is applied. So, that is the basically induced magnetic moment right. So, this is the permanent magnetic moment. All the time it is there. Only it will be absent if l equal to 0 s equal to 0 j equal to 0. So, then this there will be absent of this permanent dipole moment. So, there is atoms say inert gas. So, all are closed shell, so there all are 0, so all are 0. So, there is the permanent dipole moment, but still that material shows the magnetic property, some type of magnetic property, so that we will see.

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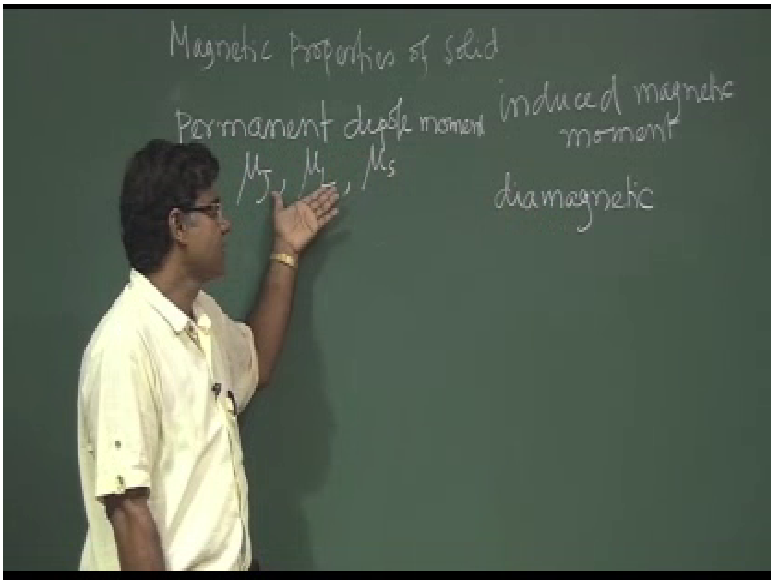

That comes due to there this induced magnetic moment is responsible for that magnetic property.

So, material is made of atom and each atom has permanent dipole moment, each material have permanent dipole moment. So, that dipole moment can be mu j, can be mu l, can be mu s depending on which one is 0. So, in some material, some atom l is 0, but s is there right. Like manganese l is 0 s is there, manganese ion. So, mu j is there. So, mu j will be equal to mu s basically. So, what about the moment it is there? But there are some materials where this permanent moment is 0, but still it shows the magnetic moment. So, that is because of induced magnetic moment.

So, this type of material is called diamagnetic material. An interesting thing is that this induced magnetic moment in presence of magnetic field, all the time it is there, whether that material is having the permanent dipole moment, or it is not having permanent dipole moment. So, this diamagnetic property basically based on this induced magnetic moment. And it is present in all the materials that why it is present, that we will see in presence of magnetic field. When apply magnetic field there will be induced magnetic moment, and induced magnetic moment is the origin of diamagnetism.

So, diamagnetism is present in all materials only magnitude can be different. Or it can be in case of permanent dipole moment in that in that material where permanent magnetic moment is there. See in that case this effect will be negligible compared to this this other effect. So, today I will discuss about this diamagnetism.

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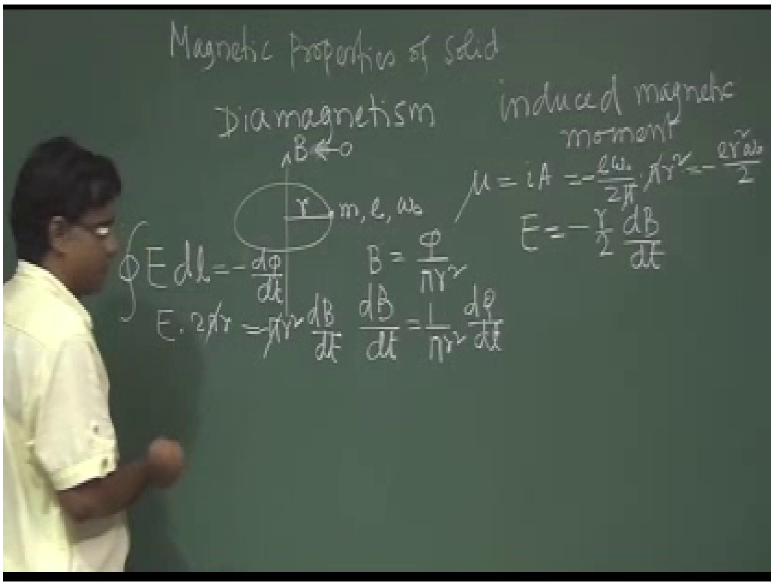

And this is based on induced dipole moment diamagnetism. So, this induced magnetic moment it comes in magnetic moment is induced in in orbit, orbital motion of the electrons. So, when electron is moving in a orbit if it is mass is M charge is e, and it is angular frequency is omega 0 right.

So, this angular momentum, so because of this motion without applying magnetic field this all the time this motion is there, and for that we get the magnetic moment, orbital magnetic moment. So, that is the mu equal to iA, and that is e omega 0 by 2 pi, that is the frequency, omega 0 by 2 pi this is the charge. And then area is pi r square. And since this is the is negative charge I will put negative. So, this mu from here I am getting basically this equal to is pi will go. So, we are getting minus e r r square omega 0 by 2, so that is the end.

So, now if I apply magnetic field say B. So, then what will happen; if I apply magnetic field B. So, this magnetic flux passes through this orbit. So, this magnetic field when you are applying; so if we vary this on this it is going from 0, it is going from 0 to B right. So, magnetic field changes from 0 to B. When there is a change of magnetic field according to lens law, there will be there will be induced EMF, and that induced EMF is proportional to the change of magnetic flux right. Change of rate of change of magnetic flux d phi by dt right, d phi by dt.

So, due to change of so here when magnetic field is going from 0 to B, there is a change of magnetic field may change of magnetic flux. So, how fast you are doing? So, that is that will decide the induced EMF right. So, induced EMF, TMF voltage it is the one can tells is your induced electric field. So, it will generate electric field induced electric field in such a way that this due to these induced EMF, induced electric field there will be current in the closed loop, there is a current in the closed loop, and that current again it will produce magnetic field right, induced magnetic field right. And that field direction will be such that it will oppose the applied field. So, that the lens law, and according to lens law.

So, there will be induced electric field over this closed loop dl. So, that is the EMF. So, that will be equal to minus d phi by d t rate of change of flux that is the induced EMF. So, this is the induced EMF right. So, this is basically E 2 pi r equal to minus d phi by dt. Now phi B equal to basically phi by a; so pi r square. So, dB by dt equal to 1 by pi r square d phi by dt. So, d phi by dt I can replaced by pi r square, I can replaced by pi r square dB by dt and this negative sign is there.

So, from here I am getting E equal to induced electric field equal to so pi, pi will go, equal to r square by r square r, r that r by 2, minus r by 2 dB by dt right. So, 0 to B so changing of magnetic field so that is provide is induced electric field right. Now this, whenever this magnetic field is applied though the charge particle is there.

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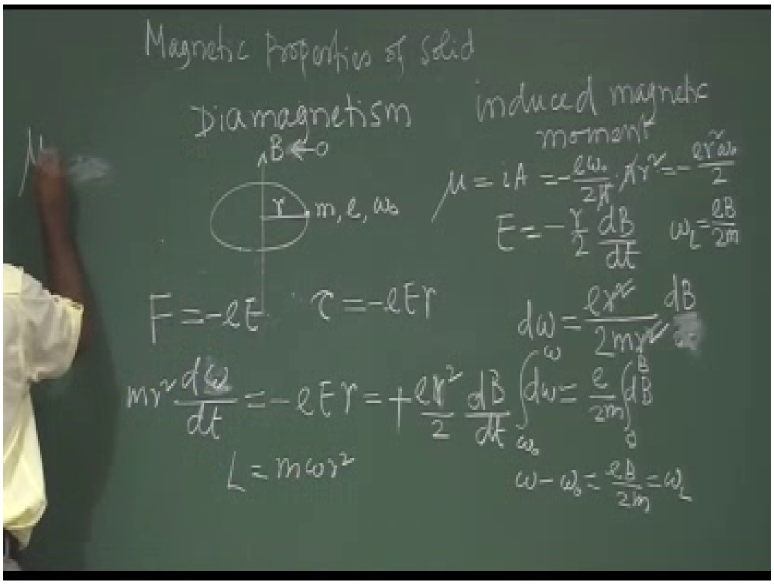

So, it is generating induced electric field. Now this electric field actually, this electric field will apply force on this on this charge.

So, that is this minus e E electric field right, this is the force. Now torque, torque will be acting on this. That will be minus e E r right. So, that will be the torque acting on the acting on this charge right. So, this torque is acting on this charge, and then when torque act on this force act on this any particle. So, it is linear momentum changes with time. Similarly, when torque works then it is linear angular momentum changes.

So, angular momentum change d, say angular momentum change angular momentum of this electron. So, this dL by dt right equal to torque. So, that is minus e E r right. And l is basically mbr means M br m omega r square right. Now this omega it is different for omega 0, because there is a additional torque due to this induced electric field right. So, this if this the new value of this angular frequency. So, dL by dt you will get I can write then d omega by dt m r square equal to this.

So, here e equal to minus e E e r and there is e I got from here. So, this plus r square by 2 dB by dt right. So, what I am getting? So, from here I can write d omega equal to d omega, equal to e r square by 2, by m r square m r square dB dt dB by dt dB by dt right. So, this r square will go. So, it is giving me e by 2 m sorry. So, dt will not be there. So, this is e by 2 m dB right. So now you take this d omega is now this.

Now, we are changing the field from 0 to B, and then it is frequency was omega 0 and it is changed to omega right. So, what I am getting? I am getting from here I am getting omega minus omega 0 equal to eB by 2 m. So, this is the value eB by 2 m is the change of angular frequencies change of angular frequency due to applied magnetic field. So, this is generally we write omega a larmor frequency. This is called larmor frequency, larmor precession frequency, actually with respect to this magnetic field this this precise in this angular momentum precise. So, angular momentum that is with this frequency, with this frequency it will precise keeping the magnetic field at axis.

So, this is the larmor frequency larmor precession frequency. So, what I got omega L, I got omega L, equal to I can write here. I think I do not need this electric field is this. So, I got basically omega L, due to magnetic field that is e B by 2 m. So, that is the change of angular momentum, change of that is the change of angular frequency due to magnetic field. Now this magnetic moment depends on this angular frequency; so due to change of this angular frequency. So, we will get the change of the magnetic moment.

So, that is the induced magnetic moment, additional magnetic moment whatever due to major it is there additionally for this we will get the additional moment.

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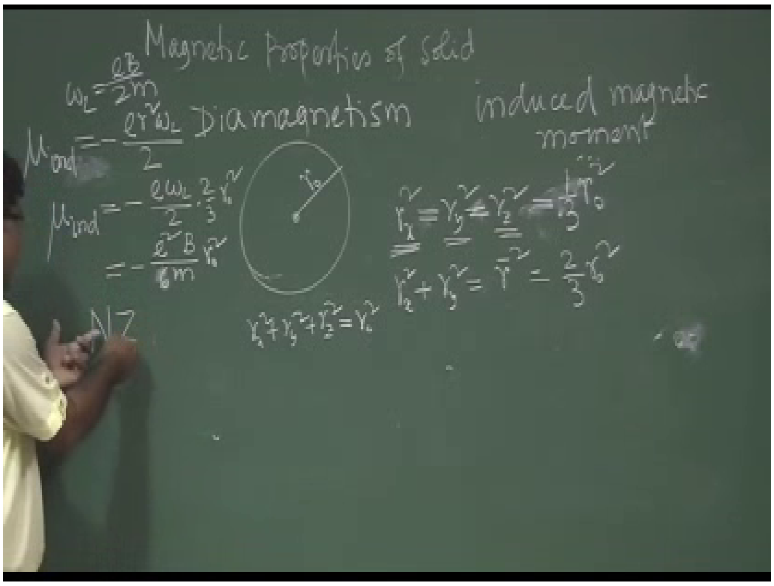

So, that is the call the induced magnetic moment. So now, I am writing induced magnetic moment equal to minus e r square omega L by 2. So, this is the induced magnetic moment in in orbital motion of this electron. So, from each orbit of the electron we will get the induced magnetic moment attached with that orbit. So, this is the origin of the induced magnetic moment. So, all metal have atom and each atom we have orbital having electron in this orbit. So, it will give the induced electromag induce magnetic moment.

So, whether permanent dipole moment is there or not it does not matter it does not depends on that. So now when this; now what happens? Now happens? Have many electrons, now each electron is have the orbit. Now this orbit size are different other different right. As well as it is it may not be circular all the time it may be leaves etc. So, if we consider the distribution of charge, electron electro negative charge is spherical. It has spherical symmetry with respect to nucleus. Then there are orbits in this mu is attached with each orbit mu induced.

Now, what will be the total induced magnetic moment for that atom; that we have to find out. Now we will be able to find out if you find out the average induced, everest average induced magnetic moment per electrons per orbit per electrons right. So, if I consider the spherical symmetry spherical symmetry of charge around the nucleus right. So, there is the basically atomic size radius of the atom are 0 right. So, what we will get? This if I take whatever the radius we have taken for this radius r, it is for a just radius of an orbit, but as I mentioned this there are many orbits having different r. So, we would like to find out the average r square right.

So, for spherical symmetry see if I take x axis, y axis, z axis: so I will get r x, r y, r z. So, r x square plus r y square plus r z square right. So, that is the r square right. So, oh for spherical symmetry, for spherical sphere so this r x, r y, r z we can take equal, they will be equal right. So, that is the, that is the equal. So, then for a orbit on a plane. So, that if I consider x y plane. So, r x square r y square equal to r square.

So, that will be the average radius of the orbit, a part is radius of the orbit. And then so this we can take, if it is radius of this atom is r 0. So, this we can take it is a one third of r 0 right one third of r 0 square. Because r x square, plus r y square, plus r z square, equal to r 0 square right. So, it is one third of this. So, this I can write then this is two-third of r 0 square. So, average radius of this orbit and this r average square, that is basically two-third of the radius of the atom. So, I can get so average induced EMF for each electron in orbit induced.

That will be minus e omega L by 2 and r square, I will replaced by r average square. So, that is two-third r 0 square. So, that is basically minus if I put this omega L equal to eB by 2 m omega L, what was that e magnetic field by 2 m right. So, e square B by 4 M, now here 2 are there. So, e to 2 the 6 I can write 6, 6 m r 0 square. So, this is the induced average induced EMF of electron. So, if I it might, if I have n number of electrons M number of electrons, sorry n number of atoms per unit volume of diamagnetic of diamagnetic material of a material, and each atom have z number of electrons.

So, I will get magnetic moment per unit volume that is M. So, this number of electrons then for each case I am getting this I have to put minus of e square r 0 square B by 6 m right. So, this is the magnetization and this negative sign magnetization is showing the negative sign.

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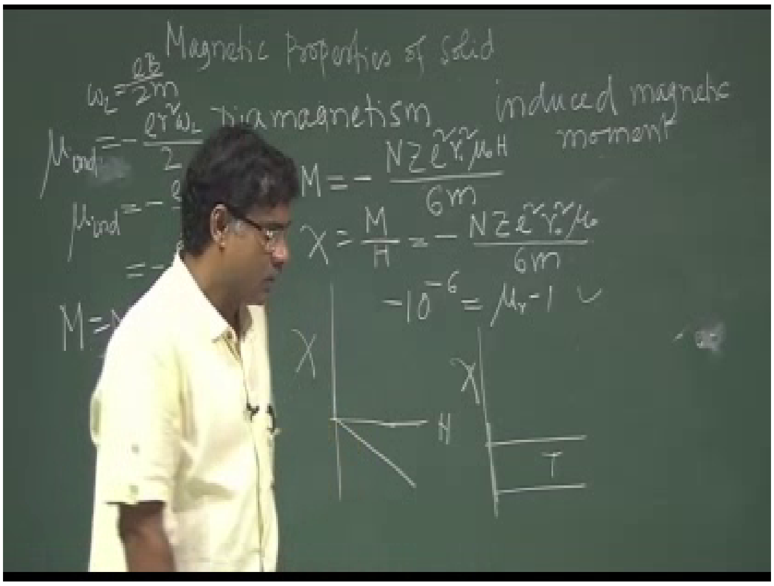

What I am getting? NZ e square then r s r 0 square mu 0 H by 6 m right. So, chi will be M by H and that equal to minus NZ e square r 0 square mu 0 by 6 m right.

So, this is susceptibility of the of the material, and subset if susceptibility is negative, and that material is called diamagnetic metal and it is the diamagnetism of the of the solids right. So, here this this chi this it is in the order of 10 to the power minus 6, chi it is the order of 10 to the power minus 6 right. And this chi you know mu r minus 1. So, mu r is slightly so this is negative sign so, mu r is slightly less than 1.

So, when a magnetic material, when a material will show the negative susceptibility and permeability is slightly less than 1, then that material is called diamagnetic material. And this susceptibility is independent of temperature, because it is purely depends on the orbital motion right. And that with temperature orbit does not change orbital motion of the electron does not change right. So, it is independent of temperature, it is very small value it is very small value, and it is present in all materials, whether permanent dipole moment is there or not.

So, if you draw chi as a function of H, H as a function of H. So, we will see this kind of variation towards negative. And if you draw this chi as a function of temperature then you will see you will see this constant value, you will see a constant value, chi is constant value, but it is negative.

So, I will stop here. I will continue in the next class.

Thank you.