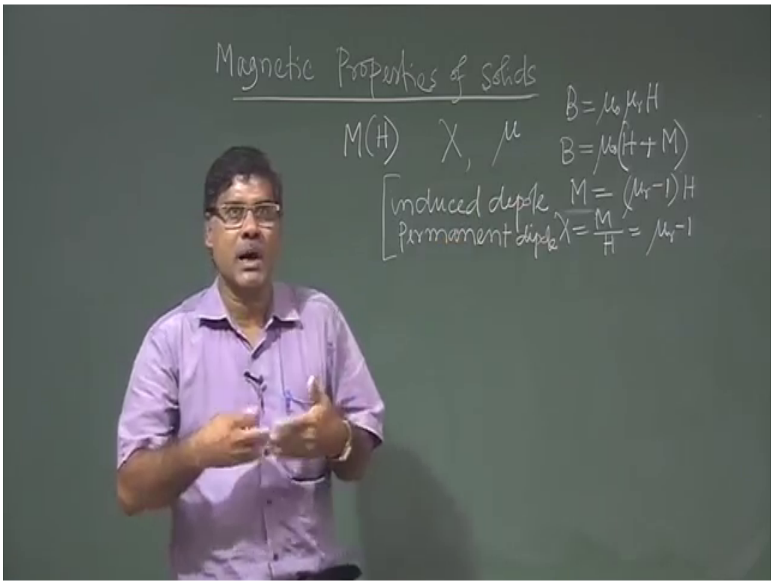
Solid State Physics

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

Lecture - 59
Magnetic Property of Solid (Contd.)

So, we have seen that this if we apply magnetic field on a magnetic material; on a material.

(Refer Slide Time: 00:36)



So we can get some parameter so that is magnetization, as a function of magnetic field. So, one should measure the magnetization of that material as a function of magnetic field. And one can find out then; chi 1 can find out and then mu 1 can find out; permeability.

The relation I have shown you; what the relation? B equal to mu 0; mu r; H and then from here, I have shown that this I have two contributions; one is this, another is fanatic materials this is magnetization. And where M is basically; what we got; this mu r minus 1 into H so then chi equal to M by H; that is the mu r minus 1.

So, if I measure the magnetization as a function of magnetic field, so I can find out chi; M by H, if I find out chi; so you will get the permeability of this material. So if I get the permeability of the material; so, then I can see the value whether it is less than 1; then I will tell it is the diamagnetic material or then I will see whether it is greater than 1. If it is slightly greater than 1; then I will tell it is paramagnetic material.

If I see this is the very very greater than 1 then I will tell it is ferromagnetic metal; so in ferromagnetic metal there are this other categories and the ferromagnetic, ferrimagnetic. So, this without knowing the details one can study the magnetic material experimentally; just measure magnetization as a function of magnetic field.

So but as I mentioned that the origin of this property comes from the atomic contribution, so, this is basically induced dipole moment as well as permanent dipole moment. So, now how; so, this as I mentioned that this metal should have either induced dipole moment or permanent dipole moment.

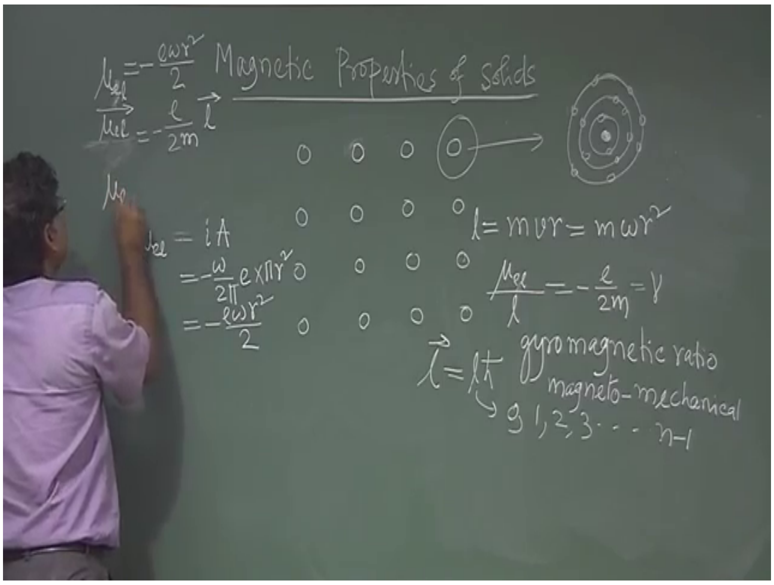
So, induced dipole moment; it comes when you apply magnetic field then this induced dipole moment occurs. But permanent dipole moment, it is nothing to do with the magnetic field; this metal itself it have this some dipole; dipole moment exists in the material. So, then we tell this the permanent dipole moment; the metal does not have dipole moment, but if we apply magnetic field then this magnetic field induced dipole moment in the material; then that is the we tell the induced dipole moment. So, this present in presence of magnetic field, this present in absence of magnetic field.

Now, when we apply magnetic field; so, in this case this induced dipole moment will occur; that is fine. But for other case, this magnetic property is decided how these permanent dipole moments are oriented towards the magnetic field. So depending on that tendency of orientation of this permanent dipole moment towards the magnetic field, so that will decide the magnetic behavior of that material; whether it is paramagnetic kind of material of this other ferromagnetic kind of material.

So to understand the magnetic property of a material; so these are the basically macroscopic point of view, one can define the magnetic material this way. But this macroscopic piece that properties comes from this microscopic property. So, its atomic level; so, one has to understand, one has to look at the material from the microscopic point of view.

So, if you take microscopy and see the material; what do you see? You will see the atoms sitting in the material.

(Refer Slide Time: 07:12)



So, now I am discussing about the origin of the permanent dipole moment. So, if I take a material see in these material; so, there will be atoms sitting at the lattice point say or will see the lattice point; atoms are associated with this lattice point; as we have seen from the crystal structures.

So, these are all this they are atoms arranged in the material. So, if I apply magnetic field; so, this atom responds to this magnetic field; how it responds there? So, let us take just one atom; so, let us see the how this permanent dipole moment coming in this material; so, definitely this comes from this atom.

So, let us see this atom; in atom what is there? If you take this atom; in atom what is there? Already I have discussed earlier. So, it has nucleus and then electrons are on the orbit etcetera, so put; you know how many will be there etcetera that you know just I have put arbitrarily. So, atoms is having nucleus and then it is having the electrons in the orbit.

So, let us take one electron; just pick up one electron which is rotating in a orbit. So, as you know; this when electrons are negative charge; it is rotating in a close path. So, it will give current and current in a closed path; it is it will give you magnetic moment.

So due to orbital motion of the electron; so this will give magnetic moment; so this magnetic moment or this orbital electron if it is mu; again I am writing mu this mu is dipole moment, it is not the permeability. So, mu I am writing this is for electron and that for orbital motion l; orbital motion it is angular momentum l. So, I am writing this magnetic moment for orbital motion; so, mu el.

So, mu el; so that is i A current in this closed loop and the area of the closed loop. And then i is omega by 2 pi; omega by 2 pi is mu means in 1 second, this electron will mu times; it will rotate. So, charge it will pass through a point mu times; if charge is e. So, total charge passed through this one point on a orbit; it is e nu, nu is omega by 2 pi.

So, after multiply with e; so, this amount of charge will flow through a point on the orbit per second; so, that is the current. And area is pi r square; orbit radius is r. So, this is giving me and this electron charge is negative. So, I will put negative sign; so, that is minus omega e, omega r square by 2. So, that will be orbital magnetic moment of one electron. So, here we have many electrons in a atom and they are in different orbit; so, here this r will take care of that different orbit.

So, this is the one relation; just let me keep it here; mu e l; equal to minus e omega r square by 2. Now as you know this angular momentum; so, these electrons are moving. So, this is angular momentum; what is the angular momentum; angular momentum mvr; this velocity.

So, this l angular momentum l; mvr, it is M; v is basically omega r. So, omega r square; M omega r square angular momentum is M omega r square. So, if I take the ratio of this mu l by l orbital magnetic moment or angular magnetic moment; mu l angular magnetic; moment. If I take this ratio and this l; angular momentum l this ratio will give you minus e by 2 m; omega r square will go, so minus e by 2 m.

So, this ratio is constant you see; e by 2 m this is the electronic charge and this is the M; mass of the electron. So, these are constant and this is called; we write say sometimes we use gamma. So, this gamma is called the gyro magnetic ratio gyro magnetic ratio or it is called also magneto mechanical effect; it is effect of factors or constant this type of; name is given this one.

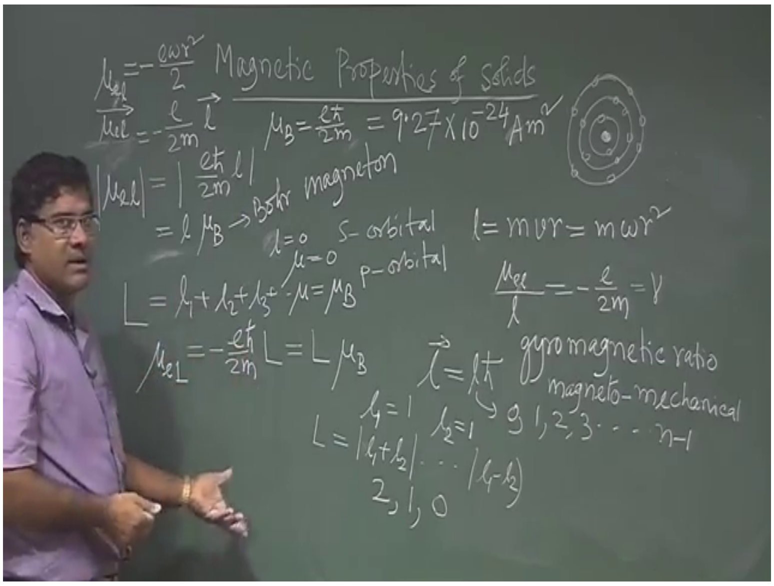
So, this is the important ratio and this is the constant for electron in orbit. So, what I got? I got basically mu l by l equal to minus e by 2 m. So, this is the connection with the angular momentum and the corresponding magnetic moment dipole moment. So, angular momentum l is; so, I can write in terms of l. So, mu; so angular momentum l what is the; so, this angular momentum it is we write; this is the vector and it is we write l h cross, its value.

So, in this case l h cross, this l is called the angular quantum number and its momentum is l times H cross; the unit of H cross momentum is in unit of H cross. So, l value can take 0, 1, 2, 3 up to n minus 1; what is n? n is the principle quantum number. So, this we can write magnetic moment also vector and this l angular momentum that also vector.

So, this negative sign is telling that direction of angular momentum and corresponding angular magnetic moment; they are in opposite direction. So, that is the significance of this negative sign; so for different orbits l are different and then you will get; different magnetic.

So, this I can write; mu l is magnitude; is minus e by 2 m; l h cross; so then if I take h cross here; so it is it is like this.

(Refer Slide Time: 20:19)



And then it is the; I can write this its magnitude; I have to retain magnitude. So, forget this sign; so, then it is giving me l, this again e h cross by 2 m; again it is constant you know; it is constant for a electron. And this we write; mu B where mu B equal to e h cross by 2 m. So, this mu B is called Bohr magneton.

So, we are dealing with this wall atom and in one atom what is the; how this magnetic moments are coming. So, this lattice we put these atoms in this lattice and then see the overall effect from the materials that will come later. So, these are called Bohr magneton; since it is constant, see its value is 9.27; most probably is into 10 to the power minus 24; it is very small value; it is ampere meter square. So, that is the in SI unit; this is the SI unit current per meter square because i A; mu equal to i A, current and that area meter square.

So, now, these electrons charge electric charge it is expressed in terms of e unit. Similarly this magnetic moment, it can be expressed in terms of a unit of mu B Bohr magneton; in units of Bohr magneton. So, now for different orbital wave we can easily find out; for l equal to 0; for l equal to 0; it is the S orbital. So, what will be the magnetic moment? it is 0; its mu will be 0; l equal to 0.

So, mu will be equal to mu B for S p; p electron, p orbitals or p orbitals and then mu equal to will be 2; mu B for p electron. So, electrons in atom are in different orbit; different orbital, wherever it is; so, it will give different magnetic moment in terms of mu B; so, we can find out.

Then this is the one source of magnetic moment in magnetic material; which is coming from the orbital motion of electrons. Second; I think I can tell you that this is from one electron. So, if atom is having many electrons; so, then following the Pauli Exclusion Principle, we can arrange them in the different orbitals.

So, to find out the resultant orbital magnetic moment; so, we have to take, we have to sum take summation of this individual one. So, that basically we get from the vector model; vector summation. So, instead of just adding this magnetic moment; one can find out the resultant angular momentum for this atom coming from these different electrons in different orbit.

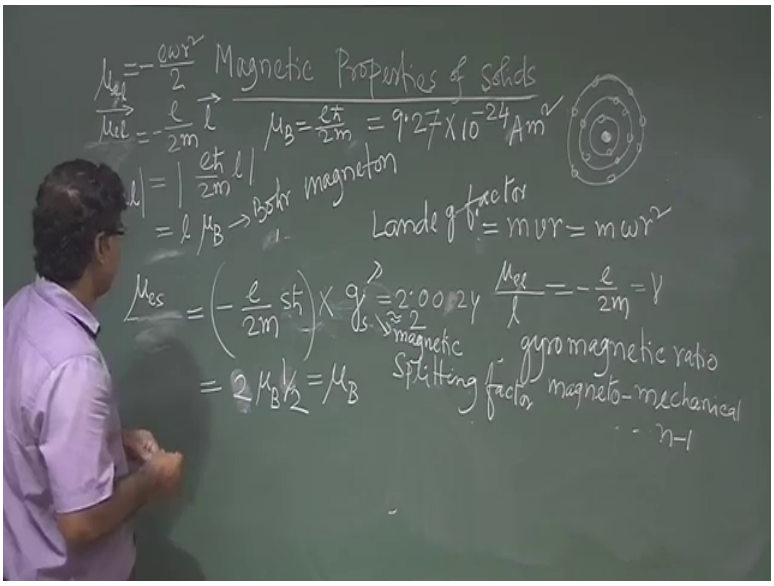
So, this l, total l resulted l it is basically l 1 plus l 2 plus l 3 etcetera. So, that will give the total angular momentum of this atom. So, then it follow the same similar same things; so then mu e coming from this angular momentum. So, that will be minus e by 2 m; l h cross; so, basically let me just. So, that will be equal to L; capital L; mu B. So, what has to find out this resultant angular momentum l and this l? As I mentioned that one can get from the vector model taking the sum of them; so if you just get 2; l 1; so, l 1 equal to say 1 and l; 2 is say 1 means both are p electron.

Then what is the resultant l; so, resultant l will be basically that we take l. So, from vectorial sum it comes l 1 plus l 2; l 1 minus l 2. So, l 1 plus l 2, it is 2. So, l 1 minus l 2 is 0; so it will go; it will have this l value will have 2, 1, 0. So, resultant l; it can have 2, it can have 1, it can have 0. So, there are three possibilities and which one it will take that depends on the state of this atom, whether it is in ground state or whether it is in exerted state etcetera, but it can have only these three values. So, which value will be for this particular state of this atom, so that will be decided depending on the state of this atom; whether it is ground state or excited state etcetera.

So, whatever relation for one atom we have used; so, just it is these relations are valid for this total; for this atom also where we will get the resultant angular momentum. Secondly, or second continuation in magnetic moment is the spin magnetic moment.

So, you know this electron have the spin angular momentum; spinning motion of the electron, about it is own axis; so, it will also give this similar relation.

(Refer Slide Time: 30:11)



So, this; so, magnetic moment due to this magnetic moment of electron spin mu e s; so, divided by S. So, it is also minus e by 2 m; it also follows this same.

So, mu S; here S; let me write small s; so this is also angular this p angular momentum. So, it has magnitude s h cross; s l can take as I showed this value s can take only half of the electron. So, here one factor is multiplied; that is one factor is multiplied.

So, that is g s; it is called g s; this factor is called Lande g-factor; the g is called Lande g-factor or it is called splitting factor; magnetic splitting factor; it is called magnetic splitting factor because under; if you apply magnetic field, then this we could apply magnetic field; the energy level was regenerate, after applying magnetic field; it is splitted; g one splitting.

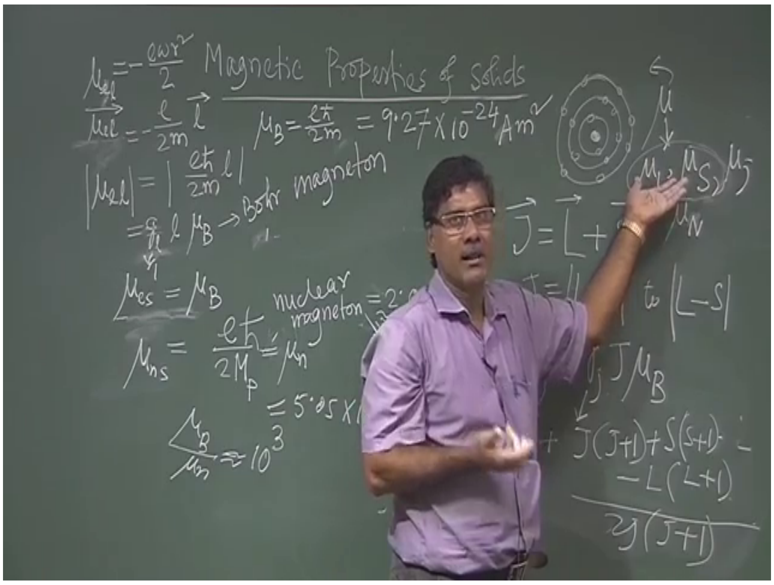
So, this splitting; this magnitude depends on this factor; magnitude is splitting this separation, it depends on this factor. So, that is why it is called splitting factor; so, for the electron in a orbit and that has spinning motion. So, this g-factor for a spinning motion of electron; its value is generally is 2.00024 kind of things or 0024; so, approximately this is taken as 2.

So, this is always 2 and this e h cross again this is mu v; so, this we are getting g s mu B and S; for electron spin that is S is half; this is half all the it is half for a electron. And this all the time this for g is taken for electron spin; it is 2. So, it is basically mu B; so, for each electron this magnetic moment of each electron; magnetic moment for spin magnetic moment or this magnetic moment due to the spinning motion of the electron, it is mu B. So, each spin will give mu B value; magnetic moment will be mu B.

So, mu e s; then mu e s is; I can write the mu e s is mu B. So, from spinning motion of the electron, we are getting the magnetic moment that is mu B. From orbital motion of the electron, we are getting l mu B. So, wherever the l; it does not matter, for each case due to spinning motion of the electron; we will get mu B. So, mu B is associated with the spinning motion of a electron, whereas angular moment varies depends on the orbital and it is independent of orbital.

So, this is the another contribution of magnetic moment in a atom; that means, in the material. So, third contribution comes from these nucleus; so, nuclear spin.

(Refer Slide Time: 35:50)



And in similar way; so the nuclear spinning motion; it comes; so, this if we write mu n; s spin emotion of the nucleus. So, that again it is e by 2 m; so now I am writing the M p; e by 2 m; M p, p is the mass of proton. So, I will get this; this will be the ratio; spinning motion of this, this will be the ratio of the nucleus.

So, here whatever I will get; so, this s it is not; I think I should write spinning motion of the nucleus. So this, whatever M that in case of electron; that is replaced by this protonomus and due to this magnetic moment; so this is called similar to Bohr magneton; it is called nuclear magneton.

And that value that is mu; n s and that value e h cross by mu p. So, this I am writing mu; so, for magnitude again I am just this minus, it comes for direction; so, this we write mu n. So, mu n value you see its value is 5.05 into 10 to the power minus 27 ampere meters. So, this is the magnetic moment comes from the nucleus; so, atom has a nucleus and electrons. So, electrons have two contribution orbital and these spin; magnetic nuclear have this; due to spinning motion of the nucleus or nucleons, so it will contribute. So, this contribution is mu B and mu n; it is more or less this factor is 10 to the power 3.

So, mu B is 1000 times higher than this mu n; so, mu n nuclear contribution angular; this magnetic moment for from nuclear contribution is very small compared to the electron continuation. So, that is why clearly we neglect this nuclear contribution; so, overall what we saw? That is magnetic moment contribution in magnetic moment for a atom, it is coming from orbital motion of the electron, spinning motion of the electron and spinning motion of nucleons; nucleus.

So, as a whole this; all these three together, it gives a moment of the atom; so, that is mu. So, it is comes from mu l for total all electrons; angular momentum and it comes from mu S; capital S because each electron is having mu B and just I cannot take some of them because they are vectors, it has directions. So, magnitude I cannot sum; so, vectorial summation we have to take.

So, S is similarly l whatever the way we have taken; S will be S 1 plus S 2 plus S 3. So, it will be victorian model; so one has to find out S and then this will be the spin magnetic moment and then other one is mu n. So, for all whole nucleons; so, one has to you will get n.

So, but these are very as I mentioned this very small value compared to this other. So, one can neglect this part. So mainly in magnetism, the contribution is coming from these two. So, this is the mu we can tell that this is the magnetic moment of this atom. Now magnetic moment of this atom, it can come; it can be written also like mu J.

So, J is the total magnetic moment; so, this is the L S coupling; it comes from L S coupling. So, it is again L plus S; J equal to L plus S; victorial sum one has to take. So, again the J can take value; L plus S; 2 L minus S and you will get this mu J for this total angular momentum in same way.

So, g this Lande g-factor g j; J mu; here this factor is not there. So, sometimes we write here g l; sometimes we write g l. So, g l is 1; basically this is 1; in case of mu S, we write you write g s. So, there is value is 2; similarly that g j. So, g j value one can find out. So, g j value is basically 1 plus J; j plus 1 plus S; S plus 1; minus L; I think I should write here minus L; L plus 1; divided by 2; j, J plus 1. So, that is the g j value; so thus you can get the magnetic moment due to angular momentum.

Angular momentum again three kinds, this orbital angular momentum, spin angular momentum and total angular momentum. So, this contribution also it comes as a mu J; so, this is the total. Now this value depends on the this coupling you know relationally. So, now this is the atomic situation; magnetic moment for a atom.

So, when this atom is put in a material in a lattice. So, situation is different; so whatever this atom is showing the magnetic moment as a isolated one; when it is put in material, it is magnetic moment, it can be different and most of the cases it become different. So, if outside for a atom; its total magnetic moment; if we are getting mu J, but inside the material; it may not show the moment mu J, it may show only mu l or only mu S.

So, that depends; this is the effect of the surrounding of the other atoms in the material; influence of the other atoms in the material. So, that we will discuss whenever it is necessary, but right now we will take that this magnetic moment of this atom in solid, in material is mu.

So, this mu can be this mu L, mu S mu J that let us forget it. So, in a material each atom have the magnetic moment mu. So, then we will discuss the different properties; diamagnetic properties, paramagnetic properties, ferromagnetic properties in coming classes. So, let me stop here.

Thank you for your attention.