Solid State Physics
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Lecture - 69
Magnetic Property of Solids (Contd.)

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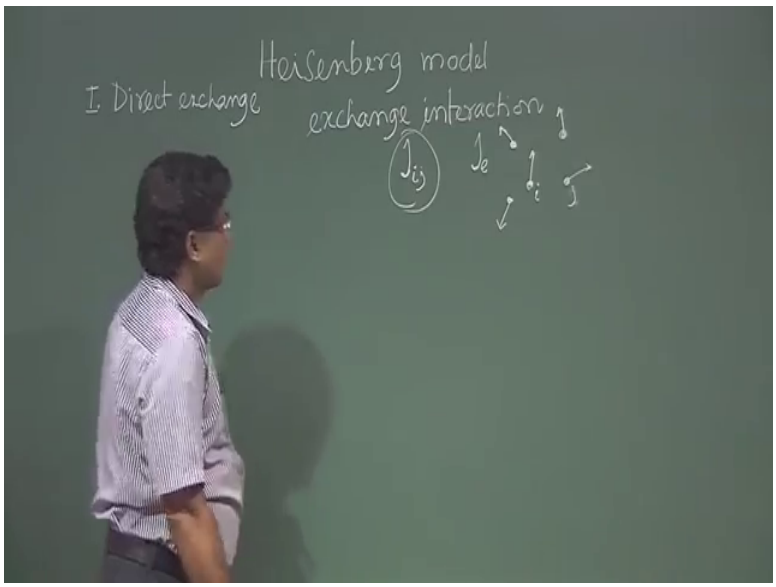

So in last class, we have discussed Heisenberg model and there this; we have seen the exchange interaction and the strength of; by exchange interaction that is will express in terms of J i J; between ith and J th spin; so, that J i J is exchange integral or exchange energy constant for particular for this two.

So, sometimes we take average; when this exchange interaction among the nearest neighbour. Then we express in terms of this average; exchange energy constant, that J. So, when I was discussing this; so, I told that this spins are; if it is ith, so surrounding J th spins are there. So, there is interaction of J th spin with the i th spin.

So, J now; J equal to 1, 2, 3, 4; so, these for all J; there is an interaction with this ith one. So, that is equivalent to the molecular field at or Weiss field. So, the way I have discussed this one, so as if they are interacting; that exchange interaction is direct exchange interaction, directly they are interacting with each other.

So, it looks it is a direct exchange interaction; so, there are two type of exchange interaction; one is called direct exchange interaction.

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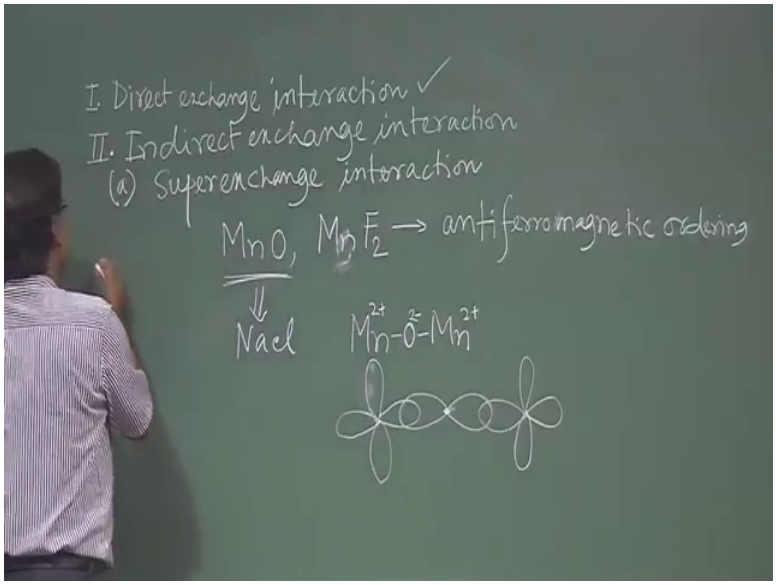

So, during Heisenberg model description; the way I have described, so that is basically direct exchange interaction; directly exchange interaction among the spins or moment. So, in terms of moment generally we do not tell because special part is involved as I described, so that is the direct exchange interaction.

Second type is indirect exchange interaction; surprisingly it is really seen; this direct exchange interaction means directly interaction among the spins is not found; most of the materials. So most of the materials shows, the indirect exchange interaction, so there are very interesting; this has come with time because different kinds of magnetic materials are there; when it is studied.

Then suppose we should not get ferromagnetic interaction or anti ferromagnetic interaction or there should not be any exchange interaction, but it is found that it is order system. So, there must be some exchange interaction and then it is analysed and found; a special type of exchange interaction and given particular name.

So, among this indirect exchange interaction; very famous interaction is called super exchange interaction. So, which type of material shows such exchange interaction? And why it is given such name? So, it is obvious that there is the direct exchange interaction.

So, it is indirect exchange interaction, so from example you will understand why it is called indirect exchange interaction.

So, this super exchange interaction it is seen in different oxide and allied solid as for example; this magnesium oxide and magnesium chloride magnesium; sorry manganese not magnesium, manganese oxide and manganese chloride. So these materials show anti ferromagnetic ordering; so there is either ferromagnetic ordering or anti ferromagnetic ordering. So, ordering is there means there is exchange interaction and it is anti ferromagnetic interaction; so, why it is called super exchange interaction?

So, in this case; so this crystal structure of this is basically manganese oxide if I take. This crystal structure of this material is basically similar to the sodium chloride structure. So, in place of sodium; manganese are there and in place of chlorine; oxygen are there. So, if you remember the sodium chloride crystal structure, we will see that manganese, ions and next manganese ions in between chlorine; in this case oxygen will be there.

So, there is no manganese; so, there is a manganese but it is too far to interact. So, in between and it is not only that; in between oxygen is there. So, it cannot interact with this one manganese with the other one directly. So, because in between this oxygen is there; since this manganese; manganese 2 plus basically ions 2 plus ions; oxygen 2 minus, so they interact; if they interact, so it has to interact via this oxygen and that is happened.

So, this manganese interact with the another manganese ions via this oxygen. So, you know this in manganese there are 5 electrons in the shell. So, d x y, d y z, d z x etcetera; sub orbitals are there. So, charge distribution of this I have shown you for d orbital; the charge distribution is like this; for d orbitals. So, then oxygen; it has p electron, so charge distribution in p electron is like this.

And then another manganese is here, so the charge distribution of this manganese and the other one, there is no direct overlapping. So, there is no direct exchange interaction; so, but there is a indirect over lapping via this oxygen. So, this manganese here this it basically polarized this oxygen electrons; oxygen charge and that polarize the other one. So, that way or just simply you can tell that; there is a overlapping of the charge of this oxygen with this manganese and with the other manganese. Thus they interact with each other; these manganese ions interact with each other via this oxygen.

So, this type of exchange interaction is called basically super exchange interaction. So, generally this type of super exchange interaction is found in ionic solid.

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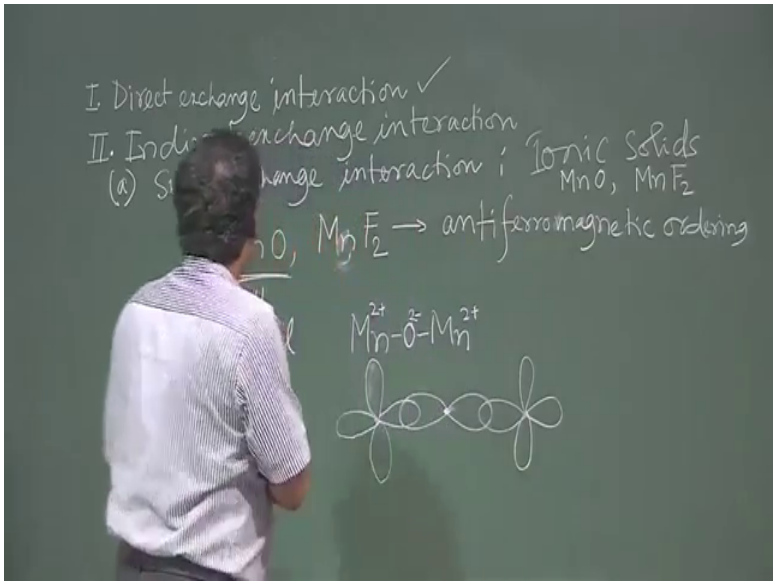

So, second type of exchange interaction; so, like manganese oxide, manganese chloride etcetera. So, these are anti ferromagnetic; this super exchange interaction basically anti ferromagnetic interaction and this manganese oxide, manganese chloride they are anti ferromagnetic material.

Now, question is this iron, copper, nickel etcetera; they are metal basically and in solid; in pure iron material, in pure cobalt material, in pure nickel material. So, atoms are at lattice point; so, even they do not interact directly, their charge distribution are not directly overlapped; so, they also interact indirectly.

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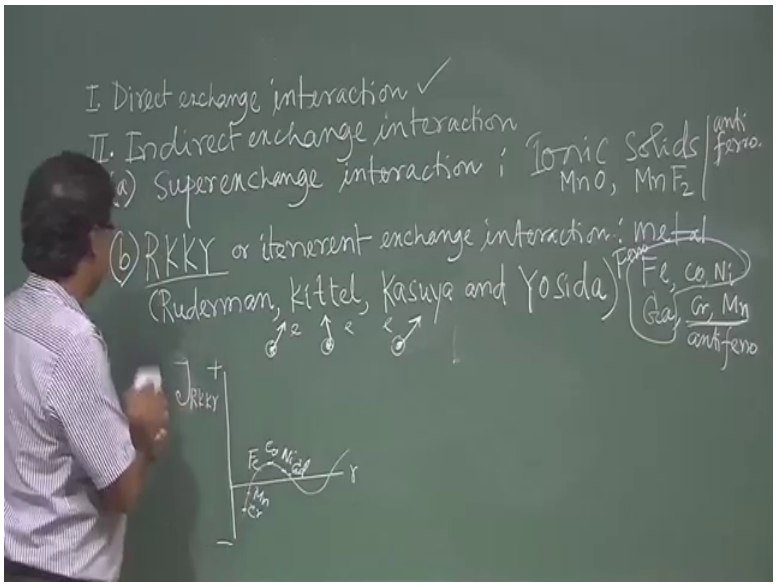

So, in case of metal where conduction electrons are there; in that case, the type of exchange interaction is found that is called RKKY or itenerent; there may be spelling mistake, but it is itenerent; conductive itinerant means conductive; itenerent exchange RKKY or itenerent exchange interaction. So, these are anti ferromagnetic interaction is found; so, RKKY or itenerent exchange interaction.

So, this is found in case of metal; so, these RKKY, it is basically after his; name of this Ruderman. So, they discovered this exchange interaction; Ruderman Kittel; that book I have given as a reference Kittel and then Kasuya and Y is Yosida. So, after this code name, so their first letter is used RKKY; exchange interaction or itenerent exchange interaction.

So, that is found in case of metal high conduction electrons are there. So, basically conduction electron conduct this exchange interaction among the spins of metal. So, this spin of ions basically not spin of electrons; in lattice we have with ion; this we have spin, now it is metal; it has conductive electron. So, they do not interact directly; they interact via this conductive electron.

So, it is telling that; so, this spin it polarise this electron and when this electron are going; moving all the time; conductive electrons. So, this free electron kind of things, so it polarised this electron and that information goes to the other one. So, it polarised as per

its state and that polarization that goes to the other one. So, via this electron its state of polarised; its state, accumulate state it influence the other one; it influence this other one.

So, that way via this conduction electron; the lattice sight, this spin of ions they are interact with each other. So, that is called basically RKKY or itenerent exchange interaction. So, it is found in; this type of interaction is found in iron, cobalt, nickel, gadolinium. So, gadolinium, iron, cobalt, nickel; these are basically metal, these are transition metal and this real arc metal and this shows the ordering because of this type of interaction.

Now, which type of ordering we will see; that depends on the distance between these lattice distance. So, very this interaction; this ordering very sensitive to the lattice distance and depending on the lattice distance, so this; it decides whether it will be anti ferromagnetic or it will be ferromagnetic. So, as you know that exchange integral; exchange energy constant or RKKY. So, this exchange generally; we write RKKY type of exchange interaction.

So, if you plot this one as a function of r distance between the lattice points. So, then it is found; its oscillatory behaviour it shows the oscillator behaviour; means it is, this kind of this oscillatory behaviour is seen. So, what does mean? So, this side is positive; this exchange interaction, this positive and this side is negative. So, when this J exchange integral is positive so then it is ferromagnetic interaction; if it is negative then anti ferromagnetic interaction.

So in case of this here; chromium, manganese; pure chromium, pure manganese; so in case of; I think chromium and then manganese yes. So, this for chromium, this for manganese and this for iron, this for cobalt, this for nickel, this for gadolinium. So, this is the strength of the exchange interaction.

So, these are negative and their distance in case of chromium; that is the distance, in case of manganese that is the distance, iron that. So, depending on the distance between these ions; so, this value of this exchange integral; it changes and its sign also changes. So, from this one can tell this chromium and manganese is anti ferromagnetic and iron, cobalt, nickel, gadolinium is ferromagnetic material; ferromagnetic interaction or ordering is found, so these are ferromagnetic; these are Ferro and these are Anti-Ferro; anti ferromagnetic.

So, it is very famous interaction exchange interaction and this; why this chromium and manganese shows the; are shows the anti ferromagnetic ordering; where as they shows the iron, cobalt, nickel shows the ferromagnetic ordering. So, it is nicely explained using this exchange interaction. So, this next type of exchange interaction that also very popular, very useful one.

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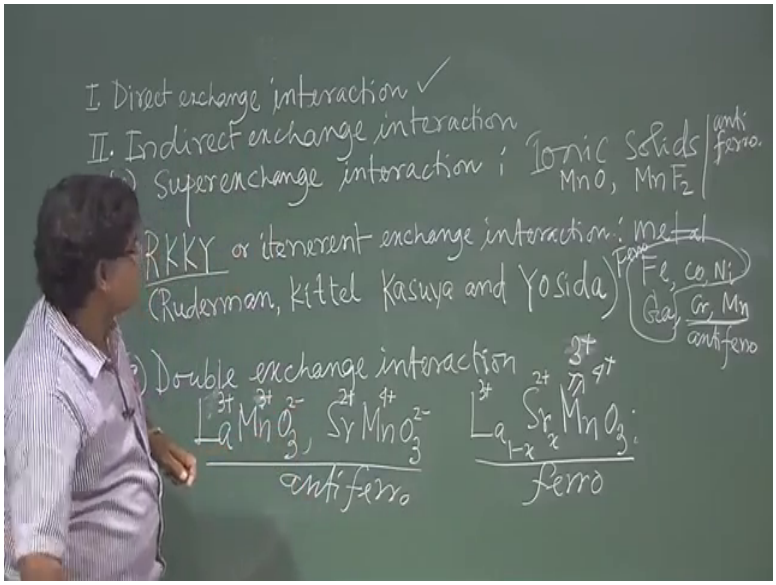

So, that is called double exchange interaction, so if you take lanthanum manganate; La M n; O 3 or strontium manganate, then these two materials shows the anti ferromagnetic property.

So, their exchange interaction is basically; super exchange interaction. So, this I told this some oxides; oxides, it is generally insulating material and they shows this super exchange interaction. So, they shows the super exchange interaction; both are super, both are anti ferromagnetic and their exchange interaction is super exchange interaction. Now, here this lanthanum is basically it is valence is 3 plus and strontium is 2 plus.

So in this case the manganese; when manganese is 3 plus; so 3 plus; so, oxygen 2 minus; so, 6; so, here plus 6; so strontium 2 plus. So, manganese will be 4 plus and then oxygen 2 minus; so, 6; here 6. So, now if you take; if you dope this lanthanum manganate with the strontium; dope means if you put some strontium in manganese; in this lanthanum manganate and some strontium will replace lanthanum. So, there that metal; we can write in this way lanthanum; it is not lanthanum 1, manganese 1; oxygen 3, this ratio.

So, lanthanum now less than 1 by x fraction and strontium occupied this x fraction; then manganese oxide, if this is the material. So, in this material here it is 3 plus, here it is 2 plus; so, some manganese will be 3 plus and some manganese will be 4 plus. So, the amount will be decided 3 plus, 4 plus by this x and 1 minus x. So; that means, in these material; mix valences are there of magnetic irons and for such case; this, now lanthanum strontium and manganate is ferromagnetic.

Now, it is very interesting; it is when this lanthanum manganate; strontium manganate, they are anti ferromagnetic. When, if you mix them together and getting this material; lanthanum strontium manganate; so, it shows the ferromagnetic. So, these two are anti ferro and exchange interaction is super exchange interaction, where as these are ferromagnetic or ferrimagnetic whatever.

Because their spin are different; I think it is ferromagnetic anyway. So, here we are getting ferromagnetic order; so, how this is getting? So, that is telling that; it is getting by other double exchange kind of exchange interaction; what is that? So, in case of; I think, I will; here I can tell you here. So, manganese 3 plus means 4 d electrons are there; manganese 2 plus have 5 d electron; now one electron goes out 4 electrons; d electrons and manganese 4 plus will 3 d electrons.

So, in crystal field this; I as told you that e g and t 2 g type of energy levels; so 5 energy levels; due to crystal field; that 2 are; 2 and this 3.

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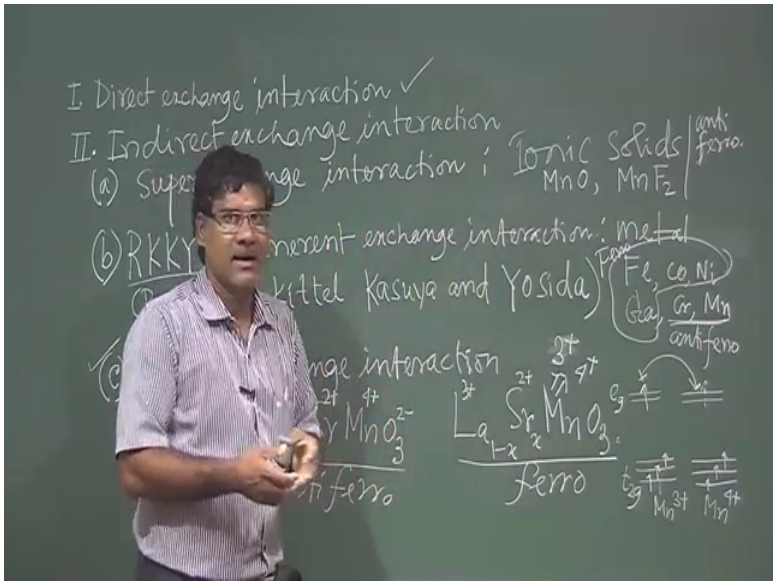

This t 2 g; I think t 2 g, yes and this is e J. So, this separation because of crystal field earlier I have discussed and that is for; if this is for manganese 3 plus means 4 electrons are there. So, this in this level; so each in each level 1, so this energy are same and another will be here and for other case; manganese 4 plus; so, here 3 electrons. So, 1, 2, 3 according to Hund's law rule; so we placed it and here there are no electrons. Now, this 3 plus and 4 plus; so, this is the arrangement of the spins; now here this spin, it can go here. When it is going here, so this backend now it can come back here.

So, this is hopping; it is called hopping, its goes from here and there. So, exchange between that M n 3 plus and M n 4 plus ions; magnetic ions via this hopping, so this exchange; so, this type of exchange interaction is called double exchange interaction. And because of this exchange interaction, this material shows the ferromagnetic ordering and for that basically we need mixed valence state of magnetic ions.

So, here it has 2 valency 3 plus and 4 plus and that is why; this type of exchange interaction is possible. And because of this exchange interaction, it is ferromagnetic ordering and this is called double exchange interaction. So, mainly these are the main exchange interaction in ferromagnetic, anti ferromagnetic; ferrimagnetic ordering. So, I think whenever you will (Refer Time: 33:56) tell magnetic property of the material.

So, you can find out exchange interaction among them, which mechanism it is following, which interaction it is following. So, in terms of that one should; so, here; what are the common materials; you know? This is the common material. So, this or other materials that their exchange interaction will be out of; one of them or there are some special interaction. So, that we will not discuss, but these are the main exchange interaction. So, I will stop here.

Thank you.