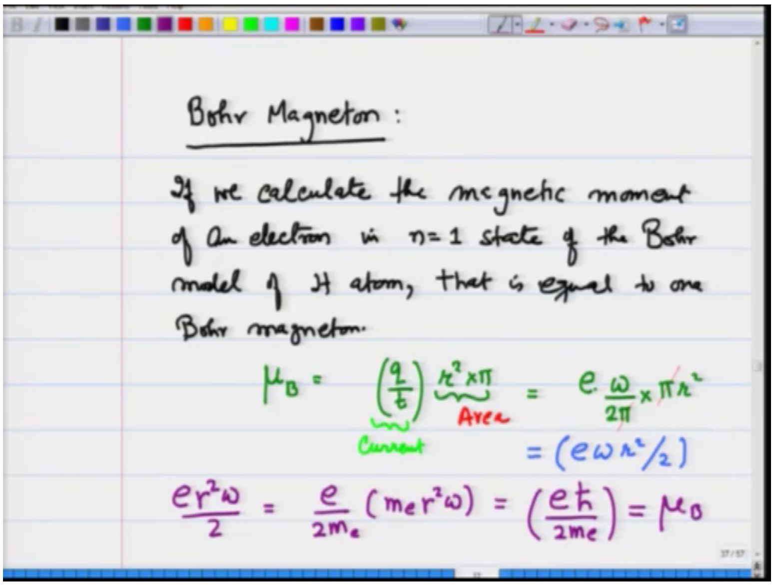
Introduction to Solid State Physics

Prof. Manoj K. Harbola
Prof. Satyajit Banerjee
Department of Physics
Indian Institute of Technology, Kanpur

Lecture – 78
Examples of performing paramagnetic susceptibility calculations

We have so far considered paramagnetic systems and I have shown you how atoms develop a magnetic moment when they are put in a magnetic field. This happens because they carry orbital angular momentum, the spin angular momentum in their electrons. And under the L S coupling we also calculated the Lande g factor and what is the magnetic moment that they will develop. In this lecture I want to give you a feel for the numbers, kind of numbers that arise when we deal with these systems.

(Refer Slide Time: 00:54)



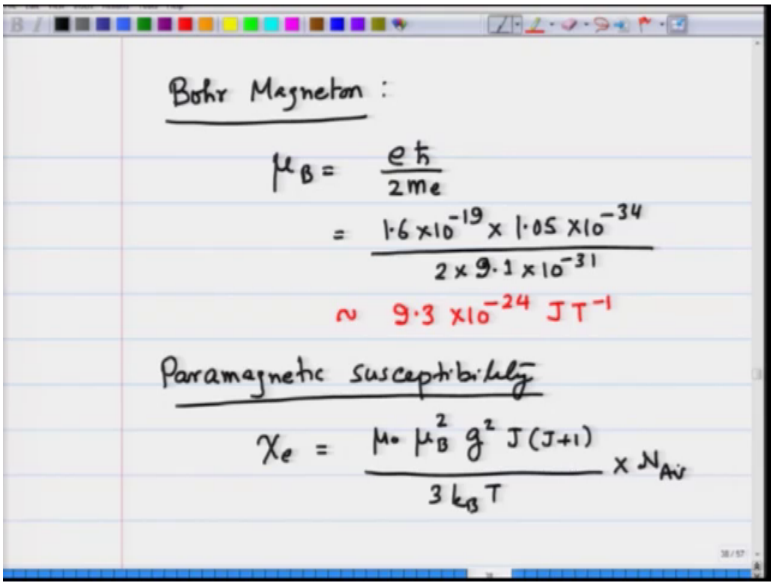
So, first concept that we used was Bohr magneton. So, Bohr magneton is defined as, if we calculate magnetic moment of an electron in n equals 1 state of the Bohr model of hydrogen atom that is equal to 1 Bohr magneton.

So, this is a number because after you solve the Schrodinger equation you know that there is no angular momentum or no magnetic moment for the n equals 1 state, but this gives us a number. So, let us see if I calculate mu B, this will be equal to the charge per unit time going around in the orbit which is equivalent to current times r square times pi.

Where this is the now, area of the orbit and the first term is the current. Which I can write as, t is the time period. So, this I can write as e times omega over 2 pi times pi r square. And this pi cancels. I get this equal to e omega r square by 2. And I can immediately relate it to the angular momentum of the system.

So, I am going to write e r square omega by 2 as, e over 2 mass of the electron times mass of the electron r square omega m r square omega is the angular momentum. So, I can write this as e and in the first Bohr orbit that angular momentum is h cross divided by 2 m e and that is a Bohr magneton.

(Refer Slide Time: 03:44)

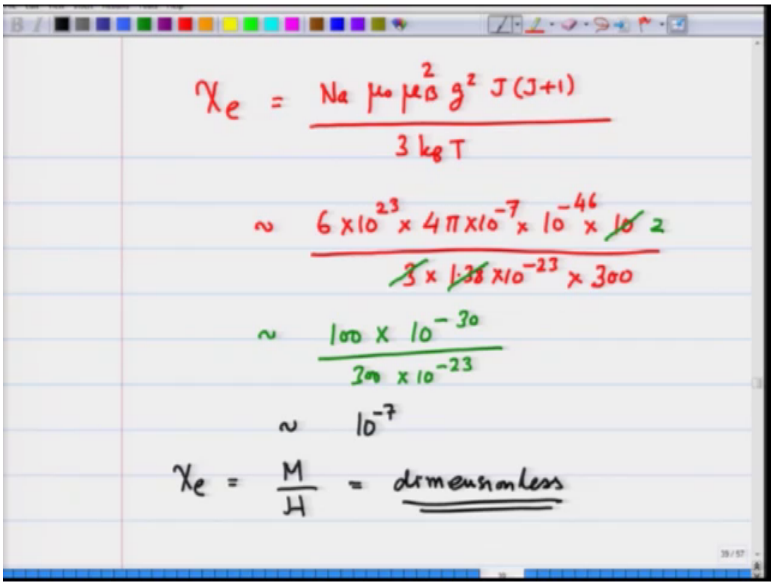


So, Bohr magneton is mu B which is equal to e h cross over 2 times mass of the electron. And let us calculate its value. This is going to be 1.6 times 10 raised to minus 19 h cross is 1.05 times 10 raised to minus 34 divided by 2 times 9.1 times 10 raised to minus 31. And this comes out to be very close to 9.3 times 10 raised to minus 24. The units are Joule per Tesla.

So, this is the kind of magnetic moment that an electron in an atom can be expected to have. Of the order of 10 raised to minus 23 to 10 raise to minus 4 Joules per Tesla and this is a unit then we use. Next, we calculated the paramagnetic susceptibility chi e which is given as mu 0, where mu 0 is the magnetic permeability of vacuum times mu Bohr magneton square times g square, where g is that Lande g factor, J J plus 1 divided by 3 k B T.

So, let us find the order of magnitude of magnetic susceptibility of this is per atom and then we multiply this by the Avogadro number to get it for per mole.

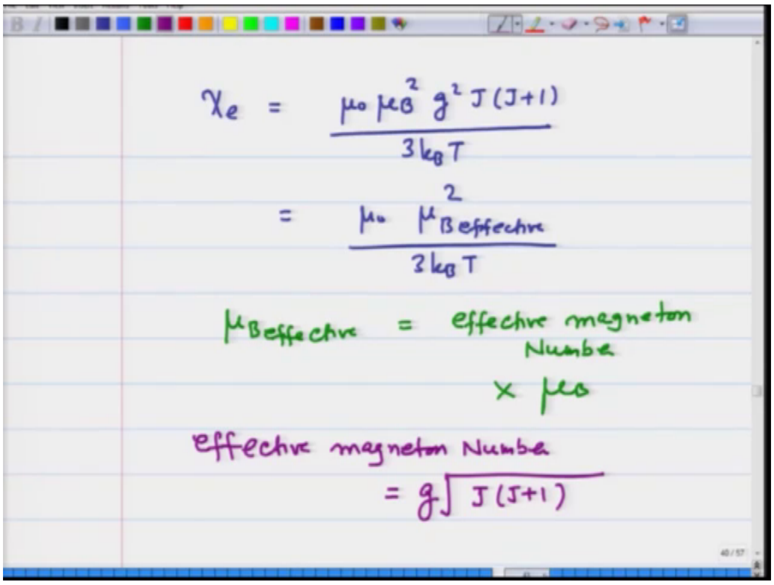
(Refer Slide Time: 05:51)



So, chi e is N a mu 0 mu B g square J J plus 1 divided or the mu B square divided by 3 k B T. And let us put in numbers and Avogadro is of the order of 6 times 10 raised to 23 times mu 0 is 4 pi times 10 raised to minus 7 mu B, we just calculated is of the order of 10 raised to minus 23. So, I am going to put it as 10 raised to minus 46 g square J J plus 1 roughly put it of the order of 10 divided by 3 k B is 1.38 times 10 raise to minus 23.

Let us take the temperature of the, room temperature 300. So, this comes out to be, let us see. Now, 3 times 1.38, that is roughly 5. So, we can cancel this, this and this as 2. Then, 6 times 2 is 12, times 48, times 4 is 48, times pi. So, that is roughly of the order of 100. So, I can write this as 100 times 10 raised to minus 23. So, minus 7, 10 raised to minus 30 divided by 300 times 10 raised to minus 23. So, this comes out to be of the order of 10 raised to minus 7. So, I can say this of the order of 10 raised to minus 7 to 10 raised to minus 5. And this is a dimensionless number because chi e is magnetic moment divided by H. And I leave it for you to check that this is dimensionless.

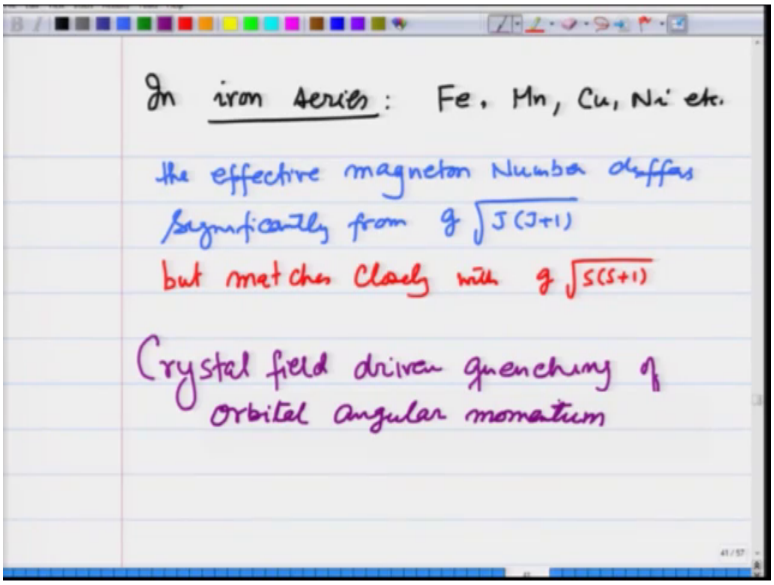
(Refer Slide Time: 08:09)



So, this is the kind of susceptibility we are talking about. Now, when I write this chi e as per atom, per atom we write this as mu 0 mu B square times g square J J plus 1 divided by 3 k B T. Then I can write this as mu 0 times mu Bohr effective square divided by 3 k B T.

Now, mu B effective is effective Bohr magneton. I can write this as effective magneton number times mu B. So, that we also talk about these atoms in terms of effective magneton number, which is defined as a square root of J J plus 1 times g. So, this is a number that one kind of compares in experiments.

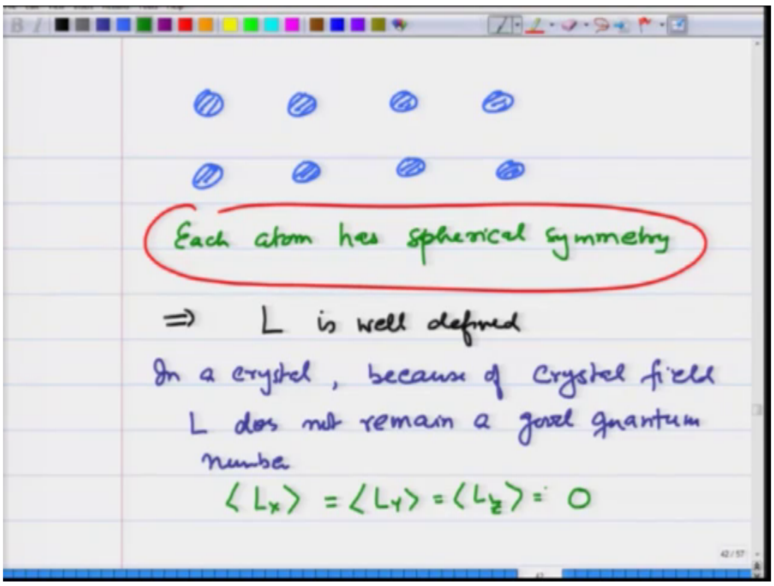
(Refer Slide Time: 09:37)



Now, it is found that in iron series which include systems like iron, manganese, copper, nickel etcetera. The effective magneton number differs significantly from g square root of J J plus 1. But, matches closely with g square root of S s plus 1.

g for S is going to be anyway too. Why does that happen? And this introduces an idea called crystal field driven quenching of orbital angular momentum. What does that mean? Let us understand that.

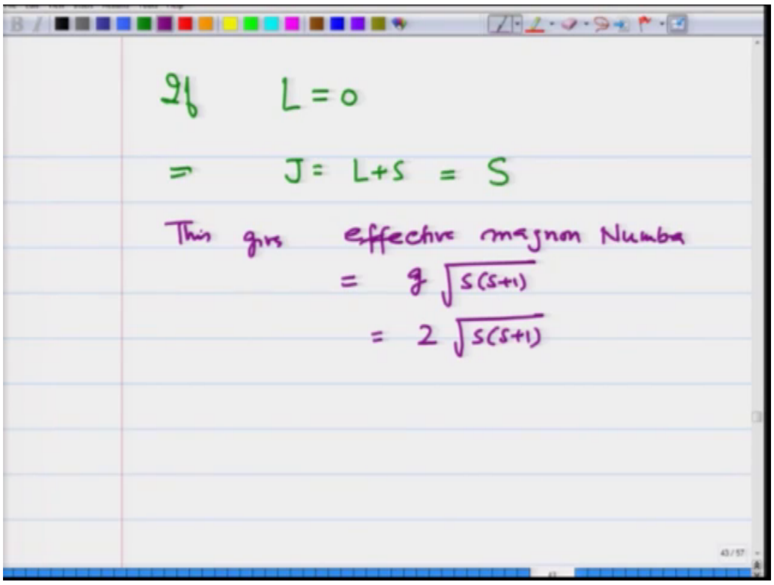
(Refer Slide Time: 11:18)



When I have these atoms in the crystal, what I have assumed in calculating the magnetic moment is that, each atom has spherical symmetry. This is the assumption. And what it means is that L is well defined.

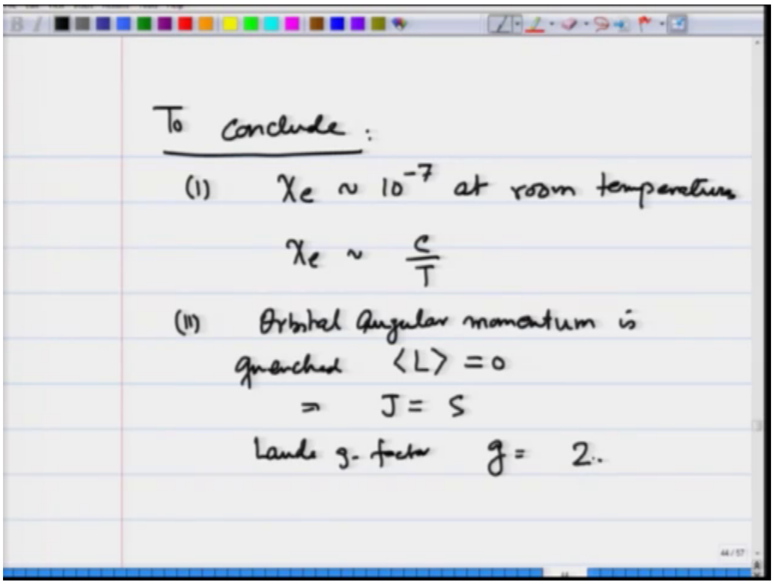
However, in a crystal the crystal field may be so strong that spherical symmetry is broken right? So, in a crystal because of crystal field and that arises basically because our atoms are affecting the field of each one of them. L does not remain a good quantum number. That means, it is not conserved and what it means is that the expectation value of L x and expectation value of L y and expectation value of L z is all 0. And therefore, there is no angular momentum.

(Refer Slide Time: 12:54)



If L is 0, this means J which is L plus S is going to be equal to S alone. And this gives the effective magnon number as equal to g square root of s s plus 1 which will be nothing, but 2 square root of S s plus 1. And in iron series it is indeed seen to be this.

(Refer Slide Time: 13:35)



So, to conclude this lecture, we have seen number 1, that chi e is of the order of 10 raised to minus 7 at room temperatures. Of course when temperature goes down, chi is going to go higher because chi e varies as C over T. And number 2, orbital angular momentum is quenched. This is the technical terms. And that means, basically L expectation value becomes 0, which is a mathematical statement of saying that L is no longer a good quantum number. It cannot be defined and this means that J is equal to S and the Lande g factor in these systems is corresponding to S and g therefore, comes out to be 2.

So, with this I conclude our introduction to paramagnetic substances. In the next two lectures I will be introducing you to diamagnetic systems and ferromagnetic systems.

Thank you.