Advanced Ceramics for Strategic Applications
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Lecture - 37
Magnetic Ceramics (Contd.)

This is the last lecture in this series of our discussion on Magnetic Ceramics. We have discussed many aspects of magnetic ceramics, in the last lecture we were discussing about the different types of ferrites.

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Magnetic Properties of a few representative Magnetic Ceramics - magnetic moments (x μ_B) per formula unit (II)

Sl.No	Formula	Theoretical	Experimental
Hexagonal Ferrites (magneto-plumbites/ magneto-ferrites)			
1.	$BaO.6Fe_2O_3$	--	1.10
2.	$SrO.6Fe_2O_3$	--	1.10
Garnets			
1..	YIG: $\{Y_3\}[Fe_2]Fe_3O_{12}$	5	4.96
2.	$\{Gd_3\}[Fe_2]Fe_3O_{12}$	16	15.20
Binary Oxides			
1.	EuO		6.80
2.	CrO_2		2.00

And we are trying to give some list of the such of kind magnetization, magnetic properties of some of the compounds particularly crystallizing in the inverse spinal structure, then magneto plum bites and then garnets garnets.

So, here are some materials of magneto plum bites the so called hard ferrite or hexa ferrites, barium hexa ferrites, that has an experimental value of the magnetic moment is about 1.1 mu b same thing also strong stronsium. So, both barium and stronsium had relatively low magnetic movement, but the most important thing is they are permanent magnets. They are magnetization and demagnetization is difficult primarily because of that anisotropic property, it is being a hexagonal symmetry starts structure being hexagonal symmetry.

Garnets structure as we earlier discussed that we have three different site, one is the dodecahedron sites, this is octahedral site, this is tetrahedral site. So, there is a distribution of the three different irons, one is the ironers and then the yitriamin, so in fact, two different irons, the both iron as well as yttrium. The iron is distributed between the octahedron, the tetrahedral sites here, sorry the tetrahedral an octahedral sites here, same in the case here in and only thing the yttrium has been replaced by gartnets gadolinium.

And one should look at these values, theoretical value of this one can calculate more or less following the same principle, what we have discussed for the inverse spinal structure of the ferrite, spinal ferrites. This is 5 and 4.96 replace yttrium by gadolinium the magnetic movement is extremely high much, much larger than anyone else. So, it is about 16 and actually one gets a 15.2, so the correlation between the theoretical value and the experiment value is quite very nice.

So, these are the different types of ferrites, we have one trio buying the oxides, like is egopium oxide and chromium oxide is also have some magnetic property. It is of a different origin of course, and, but they are also useful from technical point of view or application points of view, so this is also been listed here particularly chromium oxide is a very good material for tape recording purposes.

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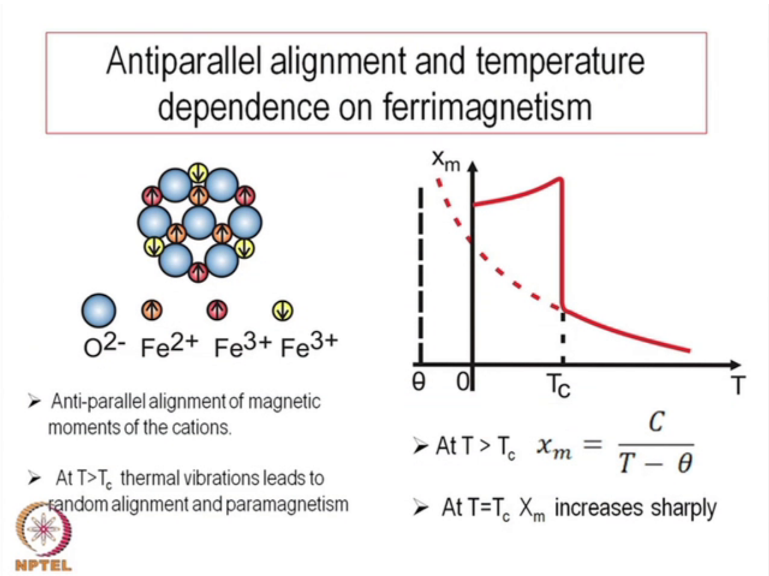

That all so far as is the list of magnetic moments are concerned here is again we have discussed these things are earlier, but it is a pictorial this is a pictorial representation of what have already discussed in case of ferrites. Anti parallel alignment of magnetic moments of the different cations for example, if it is a Fe 3 of structure you have a Fe 2 in the tetrahedral are octahedral structure here. These two are the octahedral structure and this is outsides with the tetrahedral, so half of the Fe 3 plus goes to the octahedral and goes to tetrahedral.

And here it is represented like that, so these are your once actually octahedral sites, sorry this is the tetrahedral sites, where as the red this ones are the octahedral site. So, all the octahedral sites this one, this one, this one all the octahedral sites are pointing up wards, where the tetrahedral sites pointing downwards. So, among the octahedral sites some of them are Fe 2 irons and the others are Fe 3 irons, so that is the what we call the anti parallel ordering and of course, the blue ones are oxygen irons.

So, it is because of this overlap of the p orbital's and d orbital's of the cations and their p orbital's of the oxygen enhance, this anti parallel of orientation or anti parallel ordering comes up and because the cations are different magnetic moments. So, you have lead magnetic moment unlike anti ferromagnetism, so that is we have discussed it earlier, but this is a pictorial representation of the same. At T, but there is an important consideration here that is the temperature dependence temperature dependence of the ferry magnetism, as in case of ferromagnetism we have a critical temperature, critical temperature T c.

And of course, there is a negative T c which is some something very close to nil temperature, but here this is actually the critical curie temperature, this is curie temperature. So, this is the relationship between the curie temperature and the the kind that is the susceptibility, so the susceptibility and this is related to the curie law and ferro magnetism, ferry magnetism is actually is prominent here. About T c with is the para magnetism, once again the reason basically in thermal vibration, so this ordering is no longer exists it becomes disorder and you get a very low magnetic field a magnetic magnetization.

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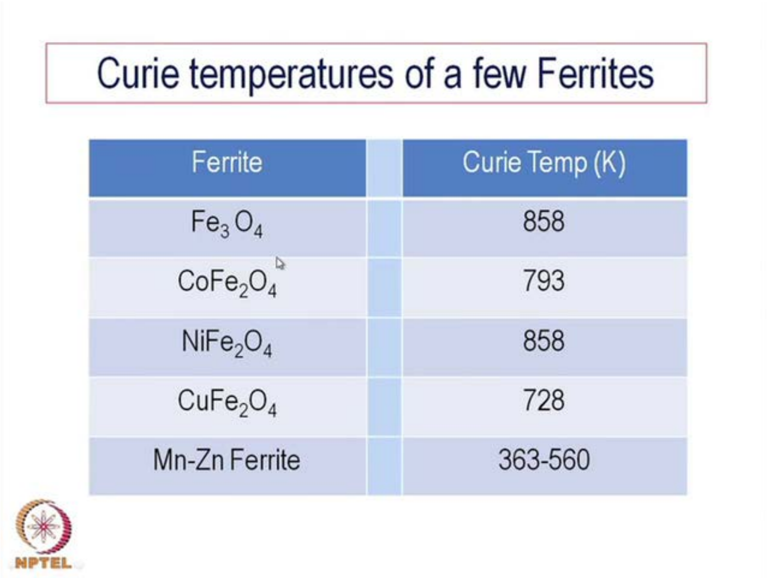

Curie temperatures of a few Ferrites

Ferrite	Curie Temp (K)
Fe_3O_4	858
$CoFe_2O_4$	793
$NiFe_2O_4$	858
$CuFe_2O_4$	728
Mn-Zn Ferrite	363-560

So, that is all the curie temperature is of two ferrites which are of importance like this a Fe 3 O 4 is over 580 k 858 k cobalt ferrite 793 k nickel ferrite 858 k copper ferrite 728 k and manganese zinc ferrite is about 363 560, just say indication of 40 b curie temperature. And what is the temperature zone of that importance or practical use, now one thing one should also remember that most of this ferrites are used not as a pure ferrite, yet pure ferrites structure, but solid solutions like this manganese zinc ferrite.

So, it is a manganese ferrite and zinc ferrite put in the solid solution and they are also having the similar properties ferro magnetic, ferra magnetic properties and hysteresis loop and so on. And they are also of importance I will give you some more examples of the solid solution ferrites so many of the actual ferrites are used in the solid solution form not as a pure oxides like this.

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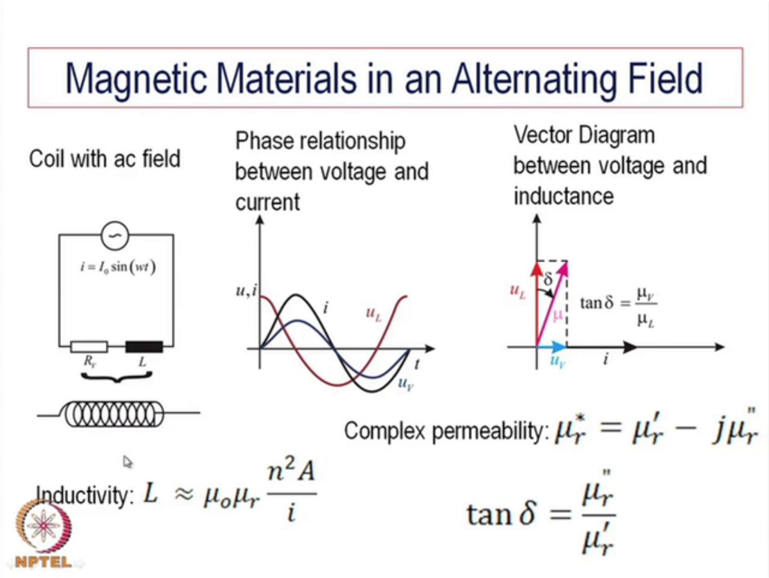

While, with this I just like to introduce magnetic materials and alternating field, ultimately the most of this particular soft ferrites are used as a electromagnets all the solenoids. And the are they are they basically max electromagnets using any electrical field, so they are magnetic response of course, changes as with the the the kind of hurriable field what one suppliers. So, it is the electrical current electromagnetic interaction electromagnetic coupling with the electrical the field which is of importance.

So, we must understand what exactly the alternating field is a to the electrical and magnetic materials are magnetic effects is very similar to is very similar to what happens in case of dielectric material. And this is also the defected diagram you have a earlier have a dielectric loss, here you have a magnetic loss magnetic loss you have the permeability a permeability which is in phases with the current of course, this is the inductance.

Here only thing is the now inductance you get is not in a a is actually 90 degree behind ninety degree behind, earlier in the dialectic thing the capacitance the capacitance or the current is leading the voltage by 90 degrees in an inductor. It is just the reverse an inductor the the current is lagging the voltage by 90 degrees and, but otherwise it is more or less the similar phenomena happens. So, you have the inductance like this inductivity l equal to mu 0 mu r n square i by A by i, and i is the current, A is the area and n is the number of tons we use in the coal.

So, this is dependent total conductance's dependent on the permeability of the magnetic material used, this is a kind of solenoid here, in which inside which a magnetic material is used and depending on that will the the R and L value of the soliniod. So, earlier we had seen in case of dielectric phenomena the R and C are in the parallel combination RC combination here is R L combination which is in series. And also you have a concept of complex permittivity permit permeability in this case mu r star equal to mu r prime minus mu j mu r double prime, and you will also get a magnetic loss tan delta.

Tan delta is a mu r double primary mu prime a these are all very similar very similar to what happens in case of the dialectic permittivity and the dialectic phenomena. So, tan delta is also a major of loss here similar to that, now why it is important the tan delta so on because many of the ferrites many of the ferrites are actually using electromagnetic field. And the electromagnetic field has a very important effect on the are not only that and whenever your frequency they are used in very different frequencies is starting from low frequency to very high frequency like the gigahertz and so on.

Some of them are also used at frequencies of the communication purpose that is micro waves gigahertz. So, whenever such frequencies are interacting with this kind of rights there is fair amount of loss and one is to understand how much loss energy loss takes place. And what is the phase lack with these are ultimately using electronic circuits, electron electronic circuits of different kind and in any electronic circuit you have different kind of career waves are various frequencies.

And so one has to understand what how exactly they behave under different alternative fields of different frequencies. So, these are shown the additional parameters here into in addition to the kind permeability and so on magnetic moments, but the tan delta value are also very important when you are trying to use them in different electronic circuits.

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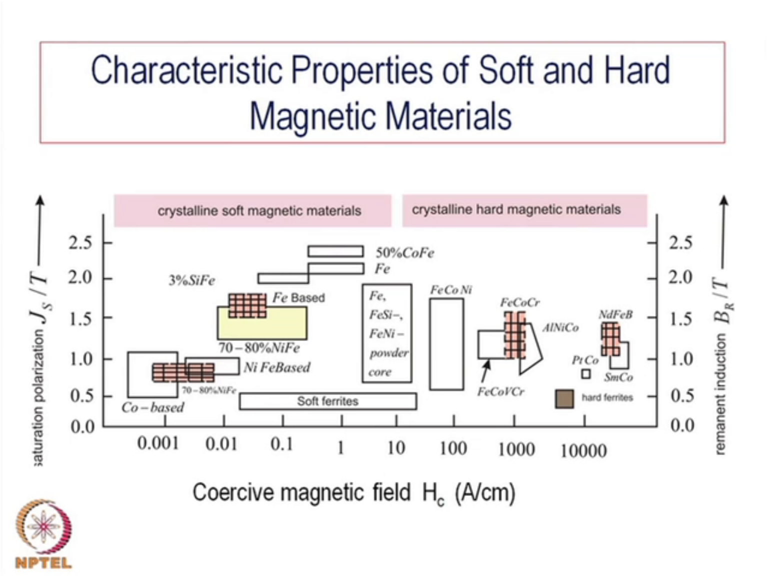

So, with these a background of their properties are let us again look at some of the macro properties of different managing materials which we have discussed so far, some of them are ferromagnetic material and some other ferri magnetic material, all of them are some interesting application. So, these are the property is how they are compared on the x axis we have plotted the coercive magnetic field that is H c from the measured from the hysteresis curve H c, and here it is the saturation magnetization the once again from the top of the hysteresis curve.

On the right you have a remenent magnetization remenent induction, so three parameter have been used, three parameters have been basically determine from the hysteresis curve, and for different material different groups of material they have been plotted here. For example, here these are cobalt based these are metallic ferromagnets, these are different alloys is a this is an nickel 70 to 80 percent nickel iron, because the three most important ferromagnetic materials are cobalt, iron and nickel, and the many of their alloys, so there the most important ferromagnetic materials.

So, they have been subdivided into two groups on can see in the top the crystalline soft magnetic materials, these are called on the left, these are all soft magnets and these are hard magnets. Because, the coercive field is much larger here and this is a long scale and find out this is a long scale for 10 to the minus 3 to 10 to the minus 10 to the plus 5. So, on this on the left side is actually what we called soft soft magnetic materials, where as are the hard these are materials which can be used for permanent magnets.

These are all permanent magnets like a or in copper nickel or in cobalt nickel here and this is or in cobalt chromium, and then a this is a very important industrial permanent magnet and nickel and there is formula and so on. Here is a this is a different group of permanent magnets, which were unfortunate not discussed here, but these are all metallic.

These elemental not oxide's not ceramics, but there are very important in the sense the very high cohesive field, extremely high cohesive field, so the magnetic strength one of the highest or best quality magnet, permanent magnets one can make out of this rare at magnets. So, mudemium iron boron for example, this is called the rare earth magnet groups there is all magnets groups in the lower only samarium cobalt or both of them are (()) rare earths.

So, this group here on the right extreme right we have the best quality magnetic material or the permanent magnets here, so where is the ceramic magnets are concern these are hard ferrites, this particular area is for the hard ferrite or exa ferrites. So, barium ferrites or strontium ferrite, so this is the hard ferrite region and one can see, although there are coercive field is very high, but there are saturation magnetization is fairly low.

So, it is difficult to magnetize and demagnetize, but the overall magnetic strength is not that large; however, it has a tremendous application, where as to talk about them the magnetism, saturation magnetize very high, very high saturation magnetize even for this soft ferrites. And here this is so far the permanent magnetisms are concerned a these are the best quality magnets one can have earlier of course, these are l equal formal R.

These are the materials which used in as magnetic materials or perm permanent magnets, now this is the soft ferrites region both of them whether it is hard ferrite like this or soft ferrite like this, they have a relatively low saturation magnetization, and remnant magnetization is also relatively low. And so they are actually related remnant normally remnant magnetization and saturation magnetization are related in the sense saturation, magnetization is slightly higher than the remnant magnetization, but these are this whole range of different magnetic materials, both in the elemental form alloy form as well as in the ceramic magnates.

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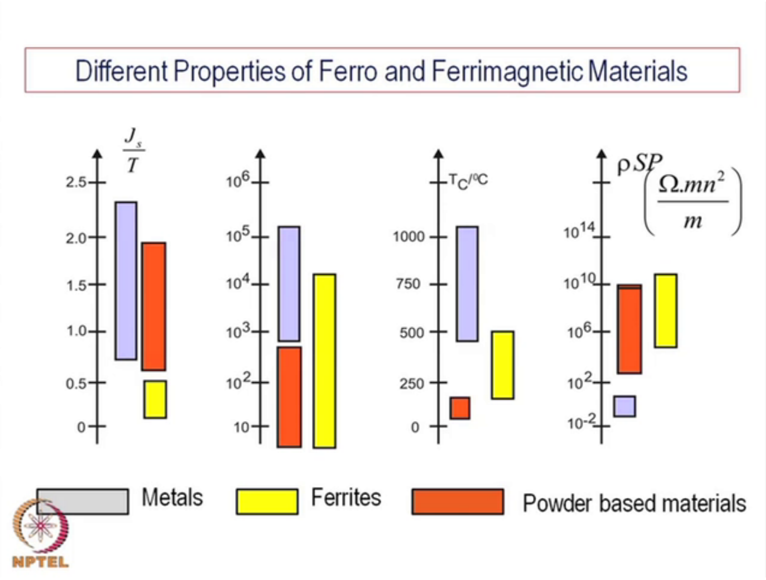

Next comparison is the different properties of ferro and ferrimagnetic materials, these are different properties one additional property are here, that is that is the resistivity the row here. This is the resistance electrical resistance of this material, there are three groups one is the metals, these are the metals the blue once, these are ferrites yellow once and the orange one powder base material in the powder form what is their property.

These are consolidated form, in the solid form, centre form, whereas these are basically in the powder form same material in the powder form, some of the powders are also important from practical point of view. So, that is why the powder properties are also given, this is the saturation magnetization by T, this is the curie temperature and this one is the resistance. Now, the most important in this case is what is the resistivity value, what is the resistivity value because metals have a very low resistance whereas, ceramics have high resistance.

And it is this property which is much more attractive from the application point of view, and this is ferrites, ferrite have a relatively high resistance, even compared to the powders. Whereas, metals have a much lower resistance much lower resistance and that causes some problems in some applications, particularly transformer applications. In transformer applications or whenever there is a lower resistance, there is a phenomena called eddy current on the surface, and that depends on the particular that depends primarily on the resistance value lower resistance, the eddy current is high.

And therefore, are there is loss is high, so the eddy current finally, gives rise to a loss in the form of heat energy, so that is the reason most of these almost all transformer course, if you have noticed all transformer course are in the laminenant form particularly the metallic course not to say ceramic course. Ceramic course are solids whereas, all metallic transformer course are insulation and in particular which are primarily used in transform as they are always laminated and then there insulated also, there is a insulating coating resinous coating on the surface.

So, they insulated each navigate from the from it is neighbor, and that is how one increases the resistivity butter effect effective resistance of the system, otherwise the eddy current law should be so high, that it will difficult design is a transfer. If this problem is not that when the one use as replace as a either a transformer course with ceramic magnets to ferrites, because of the very high resistance, you do not need laminations and eddy current loss is very low.

Not only that you can make miniaturized miniaturize transformers, what we called sometimes spot course and the so the total size becomes very low, or very small. So, this is one of the property which has to be controlled while preparing the ferrites, now one also has to understand the ferrites are mixed oxides and they contain transition metal oxides, so they have a very will valance. Therefore, any variable valance oxide has a tendency to a or they have h e property of semi conductivity, because of the variable valance and because of the hopping mechanism of conduction and so on.

And so while preparing this materials or particularly sintering at high temperature to make them a consecrated piece of solid solid one has to control the atmospheric temperature. The environment under which it is to be center, because the as seen earlier in case of discussion of our semi conductivity of oxides. It is the oxen partial pressure which controls the charge carriers concentration with electronic concentration or whole concentration and that in turn determines the electrical conductivity.

So, you want to control the electrical conductivity of these ferrites or mixed oxides, you have to be very careful about the sintering atmosphere. So, sintering of the ferrite or magnetic oxides very important sintering atmosphere is very important to control the conductivity of this electrical conductivity of the oxides are lyrical resistivity and and as just mentioned the electrical resistivity were the major consideration, why ceramic magnets have an advantage over the metallic magnets.

So, if you want to take is the full advantage of this material is one has to take care of the sintering conditions properly, these sintering conditions will change depending on which particular ferrite your used whether it is copper ferrite a nickel ferrite or it is garnet. So, all these things have to be are becoming important so far is the preparation of this material science. So, there are some intrinsic properties no doubt, but if you want to take a advantage of the intrinsic properties the preparation conduct extensive control extensive conditions have to maintain properly. So, this is how the some of the properties of the metals ferrites and the powders compared.

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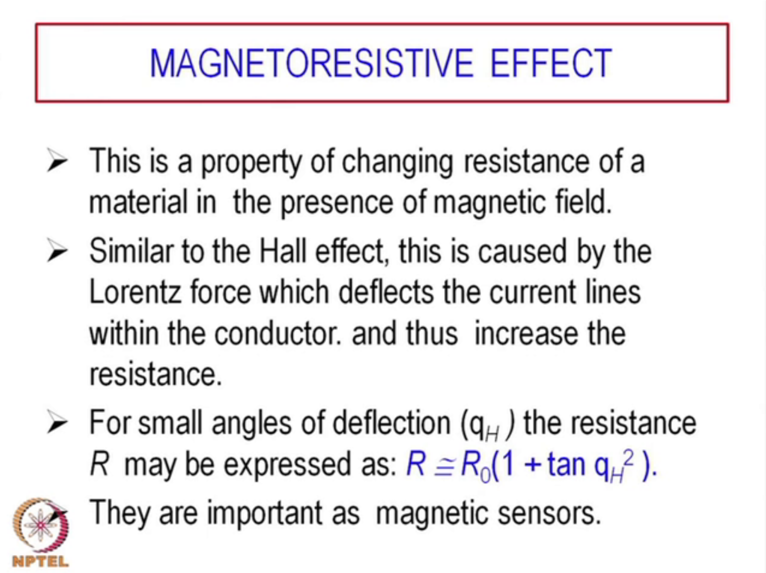

That is all more or less about the bulk materials so far is the magnetic property of the bulk material is concern, we have a different other properties that is called magneto resistive effect. This is a property of change in resistance the material in presence of a magnetic field, so there is a strong correlation between the magnetic material or magnetic field and the electrical field.

This is the something related to the hall effect very similar, the causes more or less arises from the similar phenomena which we see in the hall effect particularly particularly for semiconductors in presence of the magnetic field, the resistance changes. And one can find out, what is the hall coefficient and hall coefficient also gives us an idea which is the charge carrier, where is the negative charge carriers or the positive charge carriers. This is, so there is a correlation between the magnetic field and the mobility of the charge carriers, so one can major the hall mobility also.

So, from that analogy, similar kind of thing happens when will have a magnetic field is applied to a semiconductor or a conduct and conducting material, and the there is a change in resistance also. So, there is a change in resistance also as a result of magnetic field. So, the resistance is normally a by magnetic field and that is the property is known and then resista nce property, for small angles of deflection when that is what do it takes place in the Lorentz force which is is cause by Lorentz force deflects the current lines current lines within the conduct.

So, and thus increase the resistance, so this small a deflection the relationship the empirical relationship is like this, the resistance R may be expressed as R equalent above R 0 1 plus tan q H square, where q H is the deflection angle of reflection, in presence of the magnetic field their important as magnetic sensors. So, these materials are of very important, so far as whenever magnetic field just like a hall pro measures the magnetic field similarly this material also can be used as a magnetic sensor.

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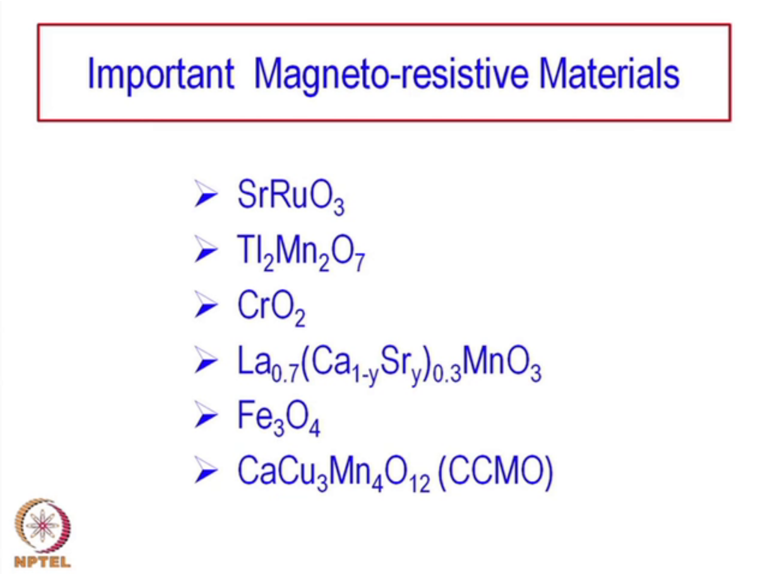

These are some of the oxides one we talk about ceramics, these are some way oxides which have some important or appreciable magneto resistive effects, strontium Ruthenate and thallium magnet chromium oxide, then lanthanam manganite L a M n O

3, which is a good semiconductor or electronic conductor and with substitution of calcium and strontium. So, both calcium and strontium, if you remembered in our fuel cell device this kind of material is also used as a cathode material Fe 3 O 4 and then you have were calcium copper manganite.

So, these are different kind of oxides we are not going to the details of such things, but the there are quite a few oxides are quite a few oxides which are this kind of magneto resistive properties and are useful and many device.

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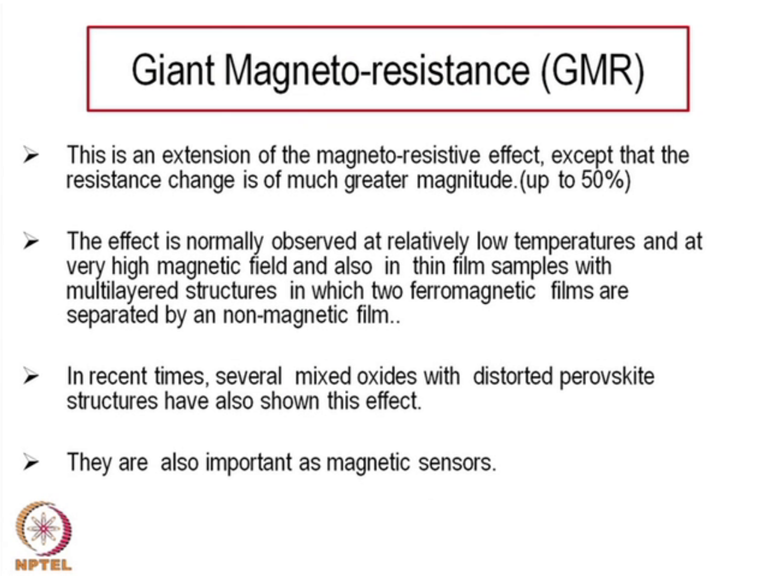

When an extension of this is called the magneto resistive are ex-a extension of these magneto resistance effect is called giant magneto resistance where the resistance change is much, much larger compared to the normal things we have which is we observed. In some under certain situation the resistance change can be as high as 50 percent and such the systems are such materials are called giant magnet resistance G M R g m r materials, sometimes also called C M R the Colossal Colossal Magneto Resistance C M R or G M R.

So, in some cases it is been found that this effect magneto resistive effect is extremely large and they can be of tremendous importance so far the applications are concerned, the effect is normally observed are relatively low temperature is it is not at room temperature relative, below room temperature and at very high magnetic field. So, whatever magneto resistive effect discussed earlier is proudly are relatively low magnetic field, but when magnetic field is very high and particularly to low-temperature and the film and the materials are in the thin-film's forms with a multilayer structure in particularly.

Then this kind of effect a Colossal Magneto Resistance or Giant Magneto Resistance Effect on is a concern are observed, which is slightly different is not exactly the same as magneto resistive effects in different materials. Particularly, the structure of this kind of systems is a multilayered structures of thin film's in which two ferromagnetic film's are separated or one are non ferromagnetic or nonmagnetic film is sandwiched between two ferromagnetic films. Such a film suggest material can be synthesized or fabricated, then those materials are supposed to have a or have been observed they are more, so a very high magneto resistance effect it is called Giant Magneto Resistance.

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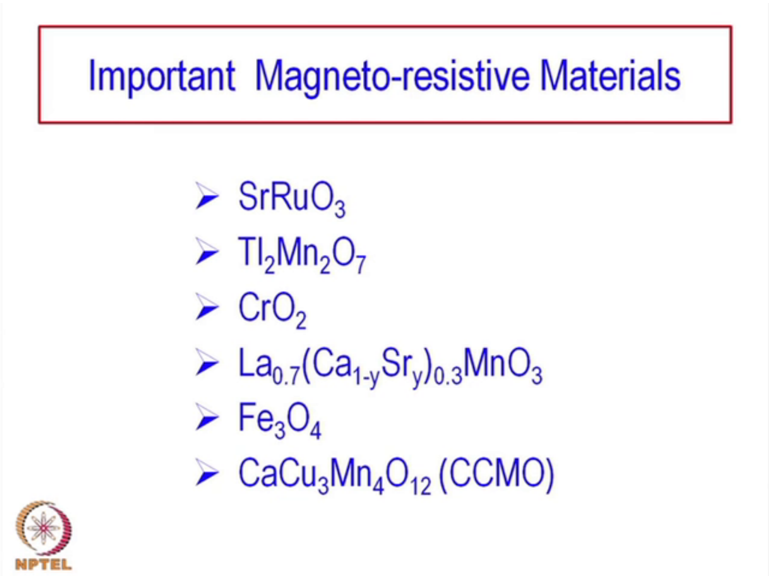

Recent times I mixed mixed oxides with these are distorted perovskite structure's impact one of the oxides which, we have discussed just now is like this lanthanum magnetite based materials also.

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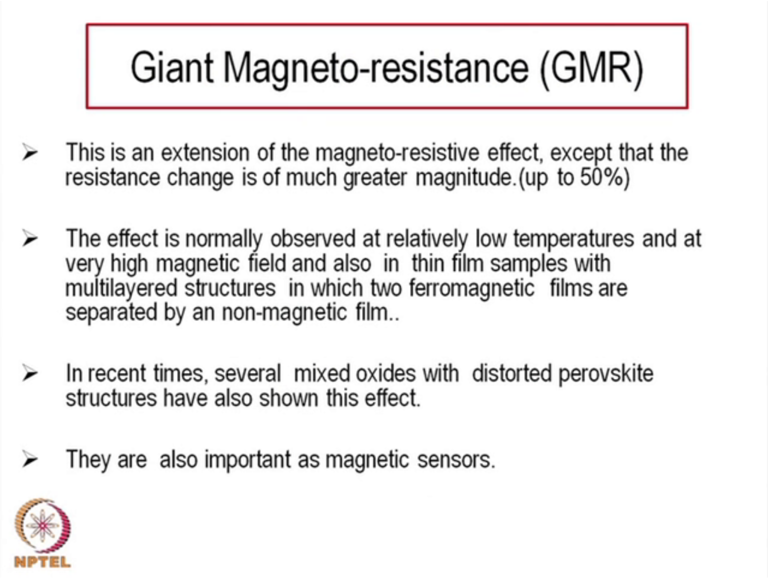

So, the magneto resistance are the advantageous to instruct it is their important, also they are also important and magnetic sensors.

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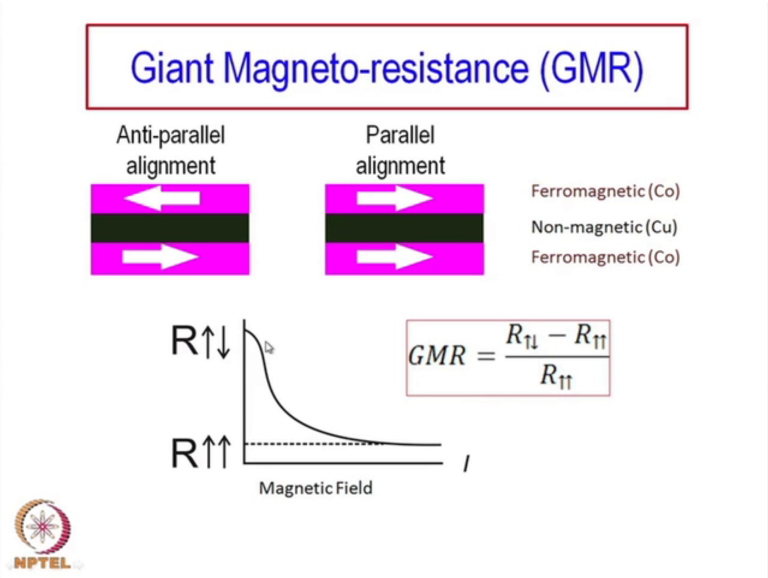

This is the structure, in fact the details of will not this discussing the magneto resistance effect a in a multilayer structure, so you have a ferromagnetic to ferromagnetic materials like cobalt film and another ferromagnetic also cobalt and then nonmagnetic film in between sandwiched between two ferromagnetic. So, and they can be aligned they can be aligned either parallelly or anti parallelly so based on that the resistance the overall resistance changes.

So, this is the kind of variation one expects, this is the anti-parallel anti parallel orientation of these these two magnetic movements here, the ferro magnetic moments under that condition the resistance is very high, where as you have a parallel orientation resistance becomes very low like this.

So, as a result of the magnetic field resistance changes and as a result the magnetic field this kind of orientation external when applying external magnetic field orientation gets change, because we are changing orientation there is resistance of this system. So, the G M R is normally expressed this is the kind of coefficient which determines the extent of G M R, the it is is very simple higher value minus lower value by the lower value, so that is another effect so far as the (( )).

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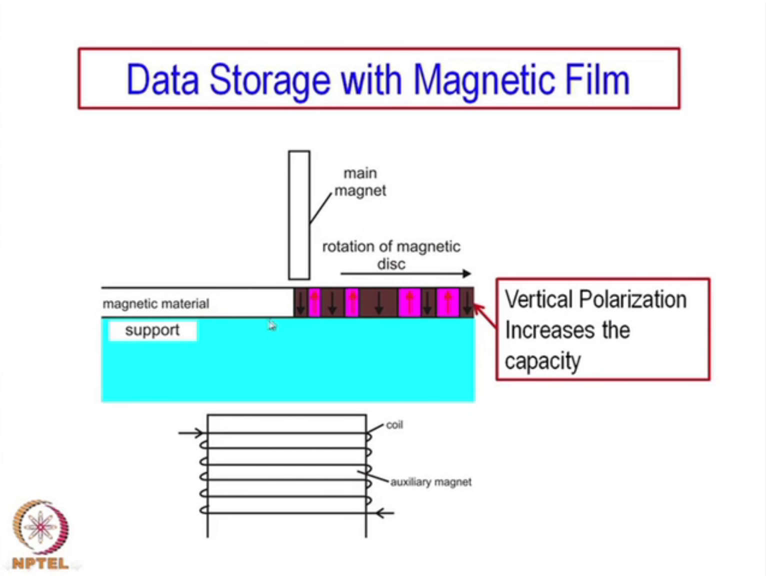

This is a just an example of some of the we come to that later, but this is only an example of thin-film's magnetic materials in data storage device as hard disks particularly and very simple thing just an example application of magnetic materials and the vertical polarization. The thin-film's are getting polarized or the depolarized, magnetically polarization must be polarized by applying a small magnet over there, and that is the main magnet.

And the disk rotates and depending on the magnetic field generated by this magnet, electromagnet either depolarize or polarize them in the vertical direction, that is the structure of they microcrystalline structure of those materials the domain structure. You have to control the domain structure of the film, so this becomes one dominant the domain, and they they can be either vertically polarized.

So, by changing they are of course, the domain over domains must to control domain size must be control domain directions the their isotropic properties must be control in such a way, that they actually get polarized in the vertical direction that, so we increase the to overall efficiency. This is a very simple a schematic of what happens in a magnetic disk, data storage device, so it is basically in the form of a binary system either polarized or depolarized.

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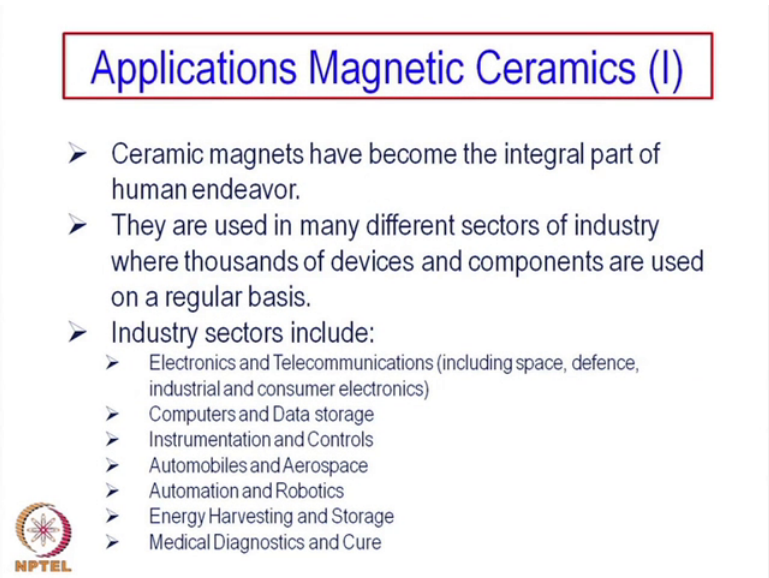

While these little backgrounder I will just list out some of the applications are magnetic ceramics, ceramic magnets are becoming integral part of human endeavor are thousands of different systems available devices which use as ceramic magnets. They are used in many different sectors of industry where thousands of devices and components are used on a regular basis, come as some of these things are listed here.

The list are not really exhaustive we have many, many different things one can think of, so the electronic centrally telecommunication area, including space, defense, industrial as well as consumer electronics. So, today's electronics I mean micro electronics cannot be thought of cannot think of microelectronic devices without a ceramic magnet, the thousands of different kind of devices have been designed and being used extensively, computers and data storage one example where just mentioned.

How the data storage device the compact takes work use in the magnetic property of some this important oxide's. The instrumentation and control once again all electronic instruments and controls use as different kind of different kind of magnetic materials either is it a miniature transformers or miniature motors. For miniaturization such kind of magnetic materials are very, very, very, very important and as I mention all ready that they have a very low a eddy current loss the overall losses very low.

In telecommunication microwave is one of the major area of telecommunication and there is a huge range of microwave ferrites, microwave ferrites are normally the garnets. The garnets which we have discussed earlier there the ghana are microwave ferrites of course, (()) ferrites are also used, but the microwave ferrites are certainly, the garnets are primarily as micro wave ferrites are used as micro ferrites. Auto mobiles and Aero space area, automation and robotics energy harvesting in-storage and medical diagnostics and cure the medical diagnostic NMR and so on.

Magnet magnet resistance, sorry the nuclear magnetic resistance is one of the techniques to diagnostics for diagnostics we have use we have discussed is to some extent in terms of value discussing about the superconductors. So, that is another area of course, but medical diagnostics several kind of instruments, electronic instruments using ferrites reduced and then the magnetic materials, magnetic materials are also used for drug delivery systems , because this kind of magnetic particles can be guided through an a external magnetic field inside the body of this human body.

And one can place it wherever is required by applying a magnetic field, so magnetic particles can be used, so magnetic particles along with the drug can be actually monitored or measure can be delivered at a particular site with the external the application of the external magnetic field source there. Basically, it is not the solid material I mean it is not the bulk material, but the fine powders fine powders or magnetic materials and more of importance.

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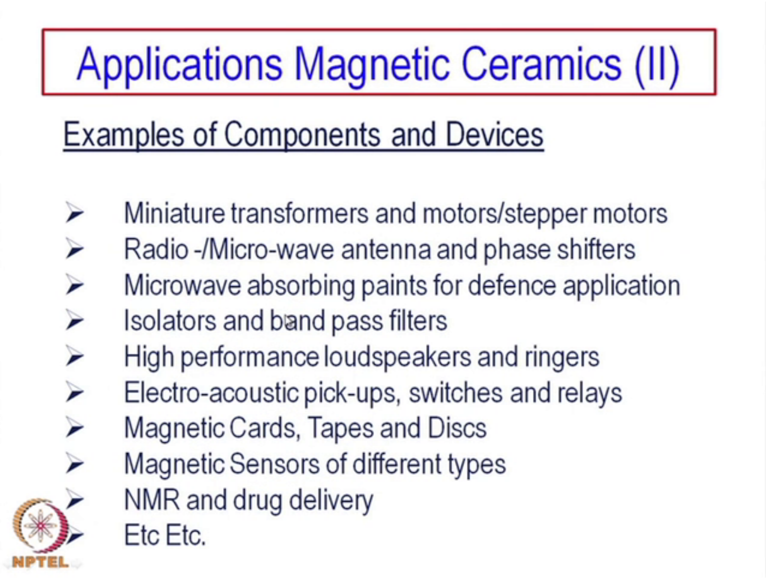

Well so, far of the components are concerned we have earlier during the sectors of different industries, but are they have some commonality, so the components are concerned. So, these are some the components which are used in different sectors they have common application areas for example, miniature transformers and motors and including stepper motors.

So, if you are talking miniature systems either transformers spot course are very, very minute are very, very small miniature systems or components one can use just magnets, ceramic magnets. Radio and microwave antenna and phase shifters and the particularly, the communication and also in the defense, microwave absorbing paints for defense application particularly some of the microwave some of the ferrites microwaves absorbing.

So, if you want to blackout black out from radar radar communication. So, one can paint it with the microwave absorbing paints and these microwave absorbing paints are nothing, but some ferrites some some ferrites can be painted on the surface of the metallic parts. And that is how the it can be a the absorb the reader waves and therefore, it cannot be seen by the other raiders, so detection becomes difficult if it is coated with some microwave absorbing paints and these microwave absorbing paint contents some of the magnetic materials or particularly defects.

Isolators and band pass filters there are very important component of electronics circuits, high-performance loudspeakers ringers, they are the integral part of for the current day our systems. Everywhere, it is used electro acoustic pickups, switches and relays, magnetic cards, ATM cards for example, the magnetic tapes, tapes and discs, have mention about it earlier magnetic sensors of different types, magneto registration sensors, than another and many other kind of sensors magnetic sensors in which magnetic materials are used, in a NMR and drug delivery other also I mention and so on, and so forth.

So, there are many, many different areas where this kind of ceramic magnets are essential components of our daily life or industrial activity, so that completes our discussion on magnetic materials whatever little time I have a I like to discuss the couple of questions or how to address such questions answers are also given here.

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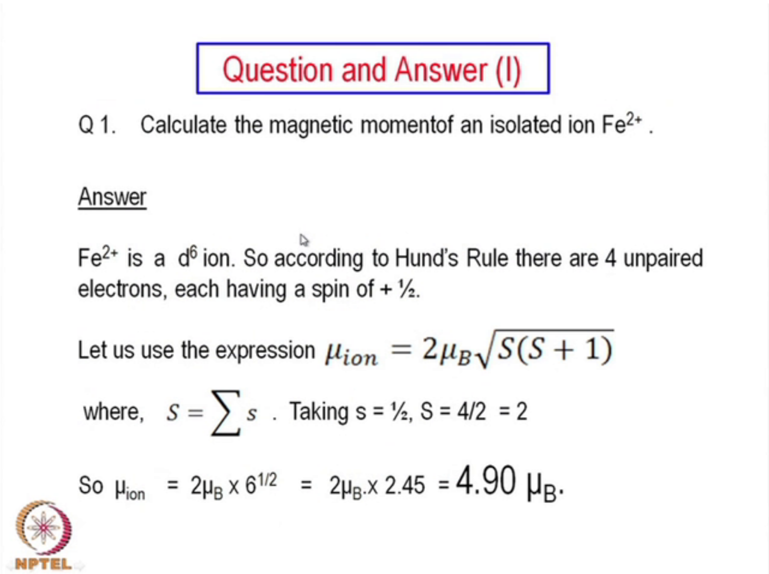

For example, the first question is a calculate the magnetic moment of an isolated iron Fe 2 plus, if you are this has already been discussed to some extent, but details are given here are for example, how to calculate the magnetic moment such an (()). It depends on the; obviously, on the d cell electrons the unpaired electron's Fe 2 plus actually d 6 ion, accordingly the Hund’s Rule there are 4 unpaired electron, each having spin of plus half, because they are all parallelly oriented.

So, two of them out of the 6 two are oriented opposite to each other, so plus and minus cancel whereas, other 4 are isolated ion or isolated electrons having plus spin plus up spin. So, there are 4 unpaired electrons with each of half spin, so if you try to find out what is the overall bohr magneton of such an the ion, this was the expression which given to earlier. Two bohr magneton into the square root of S into S plus 1, where capital S not the small s the capital S is the summation of all the small s's, how many small s's are there 4, so taking small s small as half.

So, capital S becomes 4 into half equal to 2, so S becomes 2 here, s becomes two, then just apply substitute this value in this expression, and you will get the mu mu ion the magnetic moment of that particular ion which is Fe 2 plus. So, two bohr magneton here, into root over 6 or 6 to the power of which gives you 2.45 here, and 2, so 4.9. So, the 4.9 bohr magneton is the answer for this particular question, that is calculate the magnetic moment of an isolated ion of Fe 2 plus, that will you can find. This has been listed in one of the tables earlier, but I am just showing you how it is a calculated.

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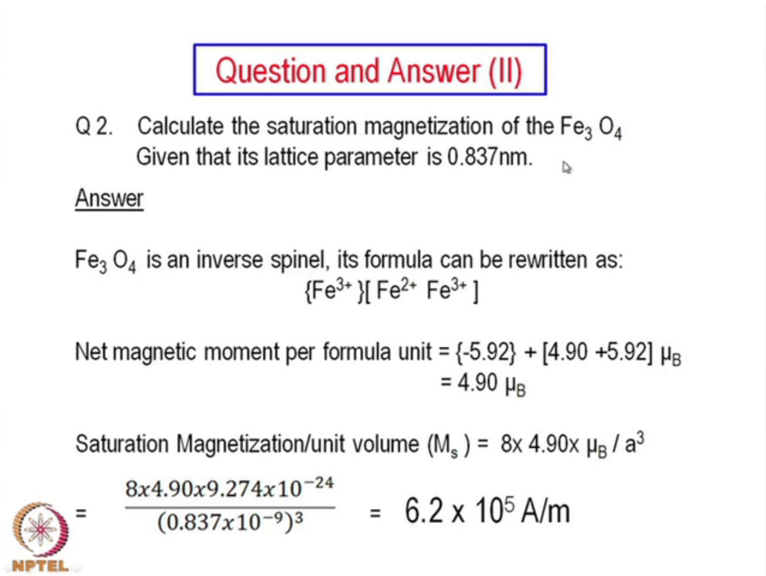

There is one more question here calculate the saturation magnetization of the Fe 3O 4 given that, this lattice parameter is 0.837 nano meters or 8.37 hangstrones. So, Fe 3 4 is a spinel is a spear types ferrite which you have both Fe 2 plus and Fe 3 plus. So, Fe 3 4 is a in a inverse spinel, it is formula can be written as Fe 3 plus plus which is outside that is tetrahedral this is tetrahedral and that is octahedral here.

So, Fe 3 plus is distributed between octahedral and tetrahedral, so Fe 3 plus cancels and only remaining is Fe 2 plus actually, the main magnetic moment per unit volume, formula unit actually this is for formula unit. This is minus 5.92, because it is tetrahedral and octahedral is 4.9 or Fe 2 plus and 5.92 is for Fe 3 plus multiplied by bohr magneton mu b. So, that gives 5.92 and 5.92 cancel and you have 4.9 bohr magneton, so for, formula unit this is 4.9 bohr magneton.

If you want to use the saturation magnetization is basically are under per unit volume, so this is how you can calculate saturation magnetization per unit volume Ms equal to 8 into bohr magneton, this is 4.9 bohr magneton 8 comes because this is a lattice parameter. So, the unit cell dimention is a cubic cubic even cubic unit cell, so the total volume of course, is the unit cell is a cube a cube is a is given a this value, so the and 8 comes here this 8 comes because in a units cell half spinel for the inverse spinel or normal spinel.

There are 8 molecules 8 molecules in an units cell, because 8 formula units 8 formula units are there, in each unit cell that is the reason it is to be multiplied by 8. So, 8 into 1 formula unit gives you this much of magnetization and divide it by the value, so that is how 8 into 4.9 and bohr magneton and this is the value of bohr magneton. And then this becomes the value 0.837 into 10 to the minus 9 cube because it is a cubic it is a cubic lattice, so by that you can get 6.2 into 10 to the 5 at Ampere parameters.So, this is the theoretical calculation through which and get what is the saturation magnetization of a magnetite Fe 3 O 4.

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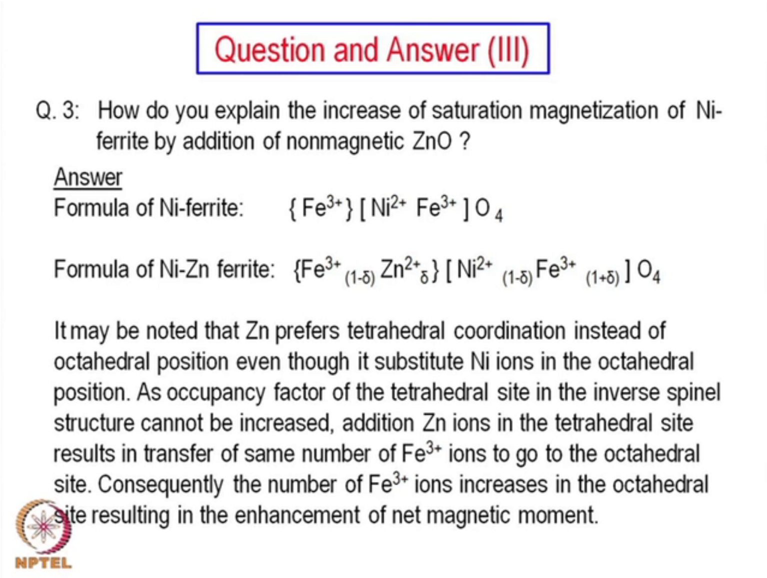

And the last question is this number three question is how do you explain the increase of saturation magnetization of nickel ferrite by addition of non magnetic zinc oxide. In a nickel ferrite you have nickel is a magnetic material and we expect some magnetization there or magnetic moment, but when you add zinc oxide to it that mean substitute part of nickel by zinc.

Zinc assets is a nonmagnetic material, there is no magnetic moment, but even then instead of a dilution effect one gets and enhancement in the magnetization and that is quite interesting ah and it should be known to everybody. That it may be noted first of all a formula of nickel ferrite is like this, NiFe2O4, so Fe 3 plus again is distributed between tetrahedral and octahedral, Ni of course, in the octahedral side. So, here you have the magnetic moment is arising from Ni 2 plus, this and this cancels channel cancels chanel right.

So, you have a only that of Ni 2 plus; however, in a formula of nickel zinc ferrite you have such we substitute part of the nickel by zinc delta amount of nickel is substituted by by zinc and that is the formula then. So, zinc is delta, so nickel 1 minus delta, but consequent to that, there is some redistribution of Fe 2 Fe 3 plus what happens zinc actually goes to the tetrahedral side, it actually it does not go to the octahedral side.

Although, it is substituting nickel in their octahedral side, but when you are substituting it actually goes to the tetrahedral side, so you have a zinc the number of zinc atoms in the tetrahedral side reduces, but in consideration of the that in part of Fe 3 plus which was 1 here, part same number of Fe 3 plus as the number of zinc ions goes to the tetra octahedral side. So, there is a transfer of ion 3 plus ions or Fe 3 plus ions form the tetrahedral to octahedral side, so this there is a dis balance here, there is a disbalance in the sense that this becomes 1 plus delta and this becomes 1 minus that delta.

So, earlier it was 1 is to 1, now it is become little less than one and this becomes little more than one and this of course, is less than 1, but this compensates this loss. And as a result you get a a enhancement in the magnetization or magnetic moment, because of this particular situation where zinc does not go into the octahedral side although it is replacing an octahedral ion substituting octahedral ion, but it does not go octahedral side instead it comes to the tetrahedral side.

And it pushes some amount of (()) to the octahedral side and as a result the dis balance is different or the there is no one is to wonder distribution here, so you get there enhancement in the a magnetic move. So, that is the reason consequently the number of 50 plus add increases and the federal site resulting the enhancement of the nature of democracy.

That is the answer to the question that brings us to the discussion on the completion the this are the end of discussion on migrating materials are discussed when types of marketing materials in general, but were focus on ceramic magnets. Ceramic magnets ferrites the garnets as well as hexa ferrites that the main form of ceramic magnets, and they have enormous, enormous application potential application already being used in many different areas as sectors of industry. Today's electronics a microelectronics cannot be thought of without the use of facts.

So thank you, thank you for your attention.