a very good morning to all of you we will continue with our discussion on magnetostatics towards the end of last lecture we started looking at different magnetic materials and let me recall magnetic materials there are three primary types of materials one are called diamagnetic materials the other one is called paramagnetic materials and the third one is called ferromagnetic materials
 so there are three primary types of magnetic response of materials diamagnetic paramagnetic and ferromagnetic
 so we started looking at diamagnetic properties diamagnetic ah let us recall that materials are made up of atoms and atoms consist of the central nucleus positively charged nucleus in which the electrons are surrounding the nucleus and the electrons are orbiting around the nucleus
 so the electrons have an orbital magnetic moment magnetic moment associated with orbital motion and also are characterized by a spin magnetic moment spin is an intrinsic property of electrons and it is just like charge and mass etc and you can picturize but this is not a very correct picture that the electron is spinning it is called spin and it has an associated magnetic moment with the spin
 so the total sum of the orbital magnetic moments and the spin magnetic moments of all the electrons of the atom gives me the total magnetic moment of the atom
 so i add up the vectorially i add up the magnetic moments of the electrons including the orbital magnetic moments and the spin magnetic moments and get the total magnetic moment of the atom now diamagnetic materials are those for which the net magnetic moment of an atom is zero no intrinsic magnetic moment that means the error the atom does not have any intrinsic magnetic moment
 so when exposed to an external magnetic field dipoles get induced by the external magnetic field now according to lenses law which we will discuss later the induced magnetic moments are directed opposite to the applied magnetic field the external magnetic field and hence they produce a magnetic field these dipoles will produce a magnetic field which opposes the direction of the external magnetic field and such media will be repelled will be pushed from regions of high magnetic field to smaller magnetic field in and homogeneous field
 so unlike um other materials which we are commonly aware of these materials get pushed from regions of higher magnetic field to lower magnetic fields and that is characteristic of diamagnetic materials
 so if you bring a diamagnetic material and apply an external field the material instead of getting attracted is repelled by the magnetic field of course the force of repulsion is very small because as we have seen before the magnetic susceptibility is very very small and this property is independent of temperature it is also present in all materials of course it get masks it gets masked in the presence of stronger effects such as paramagnetic effects and ferromagnetic effects but it is present in all materials and also the magnetization disappears when the external field is removed
 so in the absence of a an external magnetic field the medium has no magnetization and hence does not produce any external magnetic fields when you put such a medium in an external magnetic field the magnetic field magnetizes the medium but the direction of magnetization of this medium is opposite to the direction of the external magnetic field and because of this this such a medium gets repelled by the magnetic field and goes from a higher magnetic field region to a lower magnetic field region and the moment you remove the external magnetic field the magnetization disappears
 so we could write this equation m is equal to chi m h and b is equal to mu h which is equal to mu naught into one plus chi m h for this media and chi m as we have seen is much less than one and mod time is much less than one and chi m is

actually less than zero

so susceptibility is negative but much much less than one and hence the permeability mu is approximately equal to mu zero for such materials and they are an example of linear media in which b is proportional to h or the magnetization is proportional to the s vector

so that is one class of media and i have in the last lecture given your table of typical materials which are diamagnetic in character now let us come to the second class of media which are called paramagnetic in paramagnetic materials the individual atoms have a finite non zero magnetic moment

so atoms have a permanent magnetic moment unlike diamagnetic materials individual atoms have a permanent dipole moment magnetic dipole moment atoms with odd number of electrons have a net magnetic moment now in bulk materials in bulk matter the dipoles the individual dipoles are aligned randomly all right randomly and hence magnetization is zero that means although individual atoms have dipole moments in bulk matter they are all aligned in all directions randomly

so if you add the individual magnetic moments of all atoms in a small volume suppose i take a small volume containing thousands of atoms and i add up the magnetic moments vectorially of each of these atoms within the small volume i will find it to be approximately zero

so i will say the material is not magnetized because the average magnetization in the medium is zero although each individual atom has a magnetic moment they are all aligned randomly at normal temperatures and this random alignment means that magnetization is zero on applying an external magnetic field on applying the external magnetic field there is a torque on the moment on the magnetic moments which leads to partial alignment of the moments remember we have seen earlier that if you have a magnetic dipole in a magnetic field then there is a torque which acts on the magnet dipole because of the magnetic field that torque tries to align the magnetic moments with the magnetic field

so although the matter does not possess any magnetic moment the moment you put it in an external magnetic field that external magnetic field applies a torque on each of the individual magnetic moments trying to align them towards the direction of the magnetic field of course this effect is counter balanced partly by the thermal energy of the atoms the thermal energy which is which is present because of finite temperature and

so there is not a complete alignment but there is a partial alignment and when is the partial alignment then the material gets magnetized

so in the presence of an external magnetic field the material gets magnetized and the directional magnetization is along that the direction of the external field

so the magnetic moment magnetization generated in the medium is along the direction of the external magnetic field and this leads to an attraction

so the medium gets attracted towards stronger fields any homogeneous grid

so just like the common ion which gets attracted towards a magnet this material unlike a diamagnetic material which gets repelled a paramagnetic material gets attracted by towards higher strong stronger fields and

so it is exactly some something like a ferromagnetic material but it gets attract different from a diamagnetic materials now in this case magnetization depends on temperature because the external magnetic field is trying to align the dipoles towards the magnetic field the temperature thermal motion of the dipoles is trying to misalign them or randomize them

so in this case unlike a diamagnetic material magnetization depends on temperature and

so decreases with increasing temperature temperature

so in fact peer curie derived a formula 18 59 to 1906 derived a formula for magnetic susceptibility which is equal to c times mu zero by t and c is called the curiti constant

so magnetization the susceptibility is inversely proportional temperature and hence the magnetization will be inversely proportional temperature and and such materials are these are called parametric materials and just like diamagnetic materials we can write m is equal to chi m h in this case chi m mod is again much less than one and chi m is greater than zero we have again seen examples of paramagnetic materials in which i have shown that the diamond the magnitude of magnetic susceptibility is very is close to ten to the minus fourteen minus five and but it is positive

so we can again write a relation p is equal to mu h is equal to mu naught into one plus chi m into h

so in this case mu is greater than mu naught is very close to mu naught but slightly greater than u naught in diamagnetic materials mu is very close to mu naught but slightly less than mu naught

so this is the ah these are the diameter paramagnetic materials and these are formed by atoms which have a net magnetic moment in the absence of an external field they have a permanent magnetic moment but in the in the absence of an external magnetic field they are randomly oriented and

so the material does not possess any magnetization but in the presence of magnetic field they get aligned partially aligned by the external magnetic field which applies a torque on these dipoles and this alignment leads to a partial magnetization of the medium and we have magnetization proportional to the magnetic field the h vector and we have b is equal to mu h

so again such media are linear media and can be represented by an equation b is equal to mu h now we come to another very very important class of materials ferromagnetic materials now in this case also just like paramagnetic atoms have and intrinsic magnetic dipole moment primarily due to electron spin the spin of the atoms is the primary aspect which is responsible for the magnetic dipole moment now in such materials the interaction between adjacent dipoles is very strong and this interaction has a name which is called exchange interaction which has an explanation through quantum mechanics

so this interaction leads to a situation where minimum energy when neighboring moments are parallel to each other

so this exchange interaction implies that the magnetic dipole moments of individual dipole moments all get aligned parallel to each other all get aligned parallel to each other and

so there is a strong tendency for this to align this exchange interaction to align adjacent magnetic moments in the same direction but what happens is essentially when the material tries to minimize the total energy the material gets subdivided into large number of regions called magnetic domains material subdivided into regions called domains each spontaneously magnetized to a high degree

so the material gets subdivided into a large number of domains each domain is actually has a very strong alignment of the neighboring the neighboring magnetic moments and

so he is highly magnetized

so if you take a material like this actually you can divide this into a large number of layers larger number of regions each has its own this may be magnetized like this magnetic like this this is like this this is like this this is like this

so these are all individual domains within a domain there are a large number of

so each domain domain volume is about is typically 10 to the minus 8 to 10 to

the minus 12 meter cube that is the volume of the each domain approximately

so what happens is when you have a piece like this the piece has a large number of domains magnetic domains within each magnetic domain there are a large number of atoms whose magnetic moments are all aligned with respect to each other

so this this is a very strongly magnetized medium here this very strongly magnetized medium here is very strongly magnetized medium here and

so on

so the domains actually adjust themselves to minimize the total energy of the system and in that process what you find is a material like this which shows no external magnetic effects because the magnetization if you add them up they all almost cancel to zero

so there is no magnetization of this medium

so when you when somebody fabricates such a medium and takes it out of a furnace for example iron taken out of a furnace will have multiple domains in different directions which which minimizes the struc which minimizes the total magnetic energy of the system and there are large number of dipoles each dipole has its magnetic moment oriented along some arbitrary some direction

so the domain size the number of domains the shape of domains etcetera is determined by the minimization process and this number of domain formation etcetera will take place until the energy gets minimized

so if you have a big piece of ferromagnetic material you will have many domains large pieces of ferromagnetic media have many domains smaller pieces can be single domain

so the essentially it is a play between magnetic field energy and energy which is there at the interface between two different types types of domains two different orientation domains and all the total energy gets minimized and in that process the domains get aligned in random directions giving you no net magnetization

so this is a typical ferromagnetic material what is very important from this class of ferromagnetic material is ok it

so happens that there are only elements which which show only ferromagnetic elements only ferromagnetic elements are iron cobalt nickel gadolinium and dysprosium these are the only five elements which exhibit ferromagnetic and ex this explanation of this behavior requires quantum mechanics

so we will not discuss this here in this course but explanation of the ferromagnetic behavior of these materials requires quantum mechanics and these materials are ferromagnetic and there is a temperature called curing temperature which is such that for t greater than t c current temperature t c the material becomes paramagnetic and

so if you have a piece of iron which is magnetized which shows magnetic effects if you raise the temperature of the piece to more than tc which is the curing temperature of that material then it loses its ferromagnetism and becomes paramagnetic

so for iron for example t c is about ten forty three kelvin for cobalt t c is about fourteen hundred degree kelvin

so different elements have different ah temperatures

so this is a very important temperature in ferromagnetic materials that if you at any time raise the temperature of this material to more than t c and bring it back down to less than t c the material becomes paramagnetic about t c and becomes different as you lower the temperature

so this materials have a very important and very interesting characteristic of magnetization

so this is called hysteresis loop hysteresis now to explain this let me take the following ah problem

so i take a a toroid we have discussed a toroid before toroid half radius r of ferromagnetic material and i have i wind it with a coil like a solenoid closely bound wires around the entire circumference current goes in from here current comes out from here

so current is flowing through all these wires ok

so i start with a a piece of iron which is say fresh from the furnace i have a toroid of this iron piece and then i put a coil around this iron piece and pass a current now i what i want to plot is the dependence of h and b

so suppose i could i will come back to this h how do i determine h

so what i do is i pass a current through this coil as i pass a current the current sets of a magnetic field and that magnetic field magnetizes the piece of ferromagnetic material and we know that the ferromagnetic material once when a material is magnetized it produces its own magnetic field because a uniformly magnetized piece is equivalent to a surface current and that surface bound current creates its own magnetic field

so i suppose i were to plot the dependence of magnetic field on h remember for paramagnetic and diamagnetic materials b is linearly related to h they are called linear media

so now what happened is that happens is i start from this point where there was no there is no magnetic field of this inside this material nor is there any edge field now i start passing a current now remember we have an amperes lock

so let me assume that the thickness of this thyroid is very small compared to the radius

so what is ampere's law integral h dot t l is equal to i free and close h is the h field and i f enclosed is the free current enclosed that is the current which is ah which is actually conduction current passing through the wire

so if i take a loop like this remember we have done this problem before in an earlier lecture i take a radius approximately capital r and because of symmetry h will be the same at all points and as we have seen before h is in this direction in the direction of the the direction of this circle here

so i can immediately integrate this and i get h into two pi r is equal to if the number of turns total number of turns is nt and the current passing is i the total current enclosed by this loop amperian loop is there are n turns each turn carrying current i

so the h field is actually n t by two pi r into i

so as i change my current i change the h field inside and as h as i change my h field i change the b field and i plot b versus h

so i start from here when there is no current initially there was no h there is no b and i start to increase my current as i start to increase my current h starts to increase in the positive direction and i find that the magnetic b also increases and gets saturated

so let me call this a and goes to some point b

so as you increase h b increases but not linearly non-linearly and then if you increase h2s larger value it tends to saturate that means there is very little increase in b as you increase h that's a magnetization curve and

so if you see here b by h which is called the mu value is not independent of position it is dependent on which value

so b by h ratio here is different from here is different from here because this is not a straight line ok

so i go like this now what i do is i reduce the current back from i to 0.

so what happens is this material does not retrace its path but comes to a point here and let me call this c

so when i decrease my current i do not come back to the same point z this point

i do not retrace this curve but i retrace another curve
 so at this point h is 0 which means there is no current passing through the wire but the material shows magnetization there is a magnetic field and that magnetic field is because of the magnetization of the material and as you can see here when you remove the external magnetic field when you remove the h field the material still has a magnetization
 so it is a permanent magnetization you can if even if you have a if you have a ferromagnetic material apply a magnetic field and remove the magnetic field initially it was not magnetized but after applying a magnetic field and removing the magnetic field the material becomes magnetized
 so there is a permanent magnetization which remnant magnetization
 so what happens is at this point there is still a magnetization there is still a b field but no h field and if you decrease the h to negative values that means pass current in the reverse direction the current the the curve follows like a path like this and on the other side it gets saturated
 so let me call this d and this is e and then if i start to increase decrease edge the curve follows this part and then it goes comes like this and goes back
 so this is called a hysteresis loop this implies that the b field and x field are not in phase b field lacks the edge field and this name hysteresis comes from a greek word which which means to lag behind to lag behind and
 so as you can see here this field as as the h field increases the b will increased it got saturated then i should start to decrease the h field the b field decreases but not in the same fashion as when it was increasing it then becomes it hits the vertical axis at this point at this point h is zero but there is a finite b field and as you decrease the hp further to some value here d it becomes b becomes zero but x is finite and then it saturates on the other side and comes back
 so this is called a hysteresis loop and this is a very very important property of ferromagnetic materials
 so there are two important points here one is this point c and one is this point d
 so what is that point c look at at point c what it implies is even after you have removed the current from the coil that means if you remove the coil there is no current passing through h is zero but b is finite
 so this name this point c is referred to as remnants
 so as you can see here when i reduce the h field from b the the magnetic field b decreases and we hit a point c at which h is zero but b is finite and then when you decrease the h field further b becomes zero at this point d and the hysteresis loop gets completed like this now there are two important points in this loop one is this point c and one is this point d
 so let me write down what this point c is the point c that is called remnants
 so this is the point c which is referred to as remnants this is the value of b when h is reduced to zero that is as you can see here when i reduce h from here the loop does not follow the loop in this direction it comes back and hits this point c
 so this point c has zero h but a finite b and it is called dominance and it is usually denoted by this quantity b r this is the b r which is the remnants and this is a very important point as you can see here even when i have stopped the current in the loop there is still a magnetic field within the within the toroid here and that is a characteristic of ferromagnetic materials paramagnetic materials as soon as you reduce the current to zero the magnetization disappears and the magnetic field disappears here there is a magnetic field still with the with the ferromagnetic material now as you decrease h further in the negative direction as you increase h in the negative direction we will have a point d and

this point is again a very important point here which is called the this value is called coercive field

so this is the value of reverse field reverse field h required to to drive b to zero

so this is represented as hc this is the field

so remnants is this point c where the field b is finite with h is zero and cos squares field is the value of h required to make b as zero

so these are two very important characteristics of ferromagnetic materials

so if you have this is b

so let me write mu naught h here and u naught h and b have the same dimensions this is in tesla this is also in tesla

so some typical numbers here

so this is one 1.

0 this is 0.

5 this is 5 10 15 etc and this is into 10 4.

so if you have ten times ten to minus four tesla mu naught h you generate about one tesla of b field and as i will show through an example this implies very very strong fields generated by the magnetized material

so let me look at an example

so this is the toroid radius

so let me assume a radius of five centimeter and number of turns hundred

so as we have seen h is equal to n t i by two pi r and if you pass the current of say point three amperes h is equal to 100 times 0.

3 by 2 pi into 5 10 to the minus 2 which is about 100 amperes per meter

so thats 100 amps per meter and suppose ah the coil

so there is a coil here let me draw the coil now earlier remember when we were discussing toroid we didn't assume any presence of any medium here

so let me if if there was air for air core that means if there is no material here but just air the corresponding b will be mu naught h which will be equal to four pi ten to the minus seven into hundred which is equal to four pi ten to the minus five tesla

so if they core was made of air which means there is no material there then you would have got a b field which is about this is about one twelve

so its one point two ten to the minus four as you can see here compared with this ferromagnetic material it produces one tesla now let me calculate with iron core with iron core if i pass the same current of point three amperes h field is the same

so h is still hundred amps per meter now see here i must have an estimate of the mu now the one of the problems in this hysteresis is mu is not very well defined because mu as we have seen is the ratio of b to h because we had written b is equal to mu times h the the value of mu depends on where you are on this curve

so that is why such materials are called non-linear materials there is this relationship b is equal to mu h has to be used very carefully because mu is not well defined for example at this point b is finite and h is 0 which means b by h ratio is infinite at this point b is 0 h is finite

so b by h is 0

so mu goes from infinity to 0 here

so you see mu can have any arbitrary value depending on where you are

so in such materials to have a value of mu 1 has to be careful but you can actually have you can put yourself at some point of operation and define a mu

so if my relative permeability typically for this materials is about ten thousand i can have then the b which i will produce sorry p is equal to mu h

which is equal to mu naught mu r into h which is equal to four pi ten to the minus seven into ten to the power four into hundred which is about one point two tesla

so the same current of point three amperes a current of point three amperes was producing a magnetic field of one point two ten to minus four tesla with air core the same current now with the ferromagnetic materials produces a magnetic field of 1.

2 tesla

so in the presence of ferromagnetic materials because of the magnetization of medium that magnetization is extremely strong that magnetization leads us to a very very strong magnetic fields in the presence of ferromagnetic materials now suppose i had a air core and i want to produce the same field for producing same b with ion core with air core remember h is equal to for air co b by mu zero which is equal to one point two by four pi ten to the minus seven and that must be equal to n i n t i by two pi r

so the current required i can calculate from this equation i is equal to two pi r by n t into one point two by four by ten to the minus seven and that comes out to be three thousand amperes a very very large current is required to essentially produce the same magnetic field with air core

so use of ferromagnetic materials can help us to generate extremely strong magnetic fields even with very small currents

so how is this happening this is happening because the ferromagnetic materials get magnetized and those magnetization are very very strong lead to a very strong atomic currents or magnetized bound currents in this in the medium and those bond currents produce very strong magnetic fields and help us to achieve extremely strong magnetic fields even with very small currents

so this is a very very important aspect of ferromagnetic materials and

so ferromagnetic materials are used in many places wherever we need ah very strong magnetic fields such as transformers or such as loud speakers or electromagnets and

so on

so we need to have magnetic very very strong angle fields in these cases

so i must just differentiate between two types of ferromagnetic materials

so you can have two types of hysteresis loops primarily one where the hysteresis loop goes like this h versus b another one image

so difference between these two is as you can see here the question field here is very large compared to the cohesive field required for this these are called hard ferromagnetic materials these are called soft ferromagnetic materials

so they have different kinds of applications wherever you want permanent magnets i must choose hot thermometer materials because in such materials cohesive field being large implies that the field required to demagnetize the material is extremely large and

so environmental effects are very minimal in these permanent magnets they can retain their magnetization at room temperature over a long duration this software of magnetic materials are used in things like transformers or loudspeakers and

so on where you want the material to lose its magnetization as soon as you remove the external magnetic external current and these are software magnetic materials

so both such magnetic materials exist ok

so three types of primary types of materials diamagnetic paramagnetic and ferromagnetic materials and these materials have very strong magnetic properties ferromagnetic materials are very strong magnetic properties diamagnetic have negative susceptibility but very small paramagnetic have positive susceptibility

which is very small but positive and ferromagnetic materials have non-linear characteristic and hysteresis loops are very important parts of such ferromagnetic materials

so without we finished our discussion on materials and i what i want to do now is to look at a very very interesting aspect of magnetism and that is earth's magnetic field now our earth is associated with the magnetic field that means around surrounding us there is a magnetic field which is there as a part of the earth's field and this earth's field is almost like a dipole like a field produced by dipole that means just like a solenoid or a current carrying loop it produces a field and this dipole field is generated by the earth itself now people have been investigating the origin of these magnetic fields and it is believed that at the center of the earth is a solid iron core consisting of primarily of iron at about 5700 degree centigrade because of enormous pressures the material is in a solid form surrounding this is a region of liquid iron and nickel and that has a is molten in the molten form it has iron nickel and small quantities of other materials now because of differences in temperatures and pressures there is a flow convection flow of these metal metal particles within the or metal fl the fluid itself within the fluid core of the earth and this convection current leads to movement of ions and these generate currents and these currents essentially lead to the generation magnetic field

so this is the current theory called the dynamo effect and the fluid which is the which is which primarily consists of iron nickel and small quantities of other materials is actually circulating and in that circulation it produces currents and those currents leads to magnetic fields and the magnetic field is almost like that produced by dipole now there is a very interesting aspect to this magnetic field and that is the following

so let me draw for example ah

so ok

so let me draw the earth here this is the earth we all know that the earth is spinning around an axis which is inclined to the vertical

so the planets the earth is rotating in a plane around the sun is rotating around the sun in a plane in a plane and the axis of rotation is not perpendicular to the plane but inclined at about 23 and half degrees inclined

so this is called the geograph geographic north and this is called the geographic south

so equator is like this now

so happens that if you take a compass we had seen a compass before if you take a compass it does not orient towards the geographic north it orients at slightly different position and

so we define what is called as a magnetic axis this is the magnetic this is the magnetic north and this is the magnetic south and this angle is about 11. 5 degrees this angle is about

so this axis of rotation is inclined to about 23. 5 degrees with respect to the the perpendicular out to the plane and the magnetic axis is slightly displaced with respect to the geographic axis by about 11. 5 degrees

so the if you take a magnetic needle it the north north directional magnetic needle does not point exactly towards the geographic north but slightly tilted what is also found is that the north magnetic pole is called north magnetic it is called north magnetic but the that means the north pole of the magnetic compass points toward the direction

so that must correspond to the south pole of the dipole magnet

so if i were to draw a dipole magnet here this will be the south pole and this

will be in the north pole

 so if i let me draw another figure here showing the field lines what it look like

 so i have the uh earth and the um the the geographic one this is the

 so not geographic not magnetic south geographic south magnetic

 so the equivalent magnet looks something like this this is south this is north if i were to draw field lines you have something like this its almost its approximately dipolar

 so the field is not exactly type it like a dipole its its approximately dipolar

 so suppose you were to take a magnet a compass needle at some point what you see is it points in a slightly different direction

 so let me show you through a demonstration here

 so let me take a pair of pencils

 so this red pencil points towards the north geographic north and the black pencil is pointing towards the geographic east this red pencil is pointing towards geographic north and black pencil is produced is pointing towards geographic south east

 so if you take a magnetic needle here if you take a magnetic needle it will point like this if if the magnetic needle was free to rotate in any direction it will point like this it is not pointing towards the geographic north nor is it in the horizontal plane it is pointing like this

 so let me repeat this is the geographic north north north direction here this is the east direction here and if i take a magnetic compass and allow it to be freely rotating in any plane what i find is it does not line the horizontal plane but it points slightly downward and in this direction

 so now i define two angles the angle between this vector and the horizontal plane which is this angle is called the dip and the angle between the horizontal line and the geographic north is called the declination

 so let me recall again here

 so if i if i if i this is the magnetic field direction i go up to the horizontal plane i get the dip and i move this angle towards the geographic north i get declination

 so there are two angles here from the direction of the b vector i move a certain angle which is called the dip to come to the horizontal plane

 so the angle between magnetic vector and the horizontal plane is called dip the angle between the horizontal component and the geographic north is called the declination

 so these two angles represent the direction of the magnetic field at any point

 so geographically at different points you will have the definition of a dip which is this angle between the magnetic field direction and the horizontal plane and a declination between the horizontal component of the magnetic compass and the geographic north

 so if you allow the magnetic needle only to rotate in the horizontal plane it will point like this here and not like this it will point like this and this angle is actually the declination declination and one has to correct this for in geographic conditions because this direction of the magnetic compass is not exactly the geographic north but it is a magnetic north

 so these two angles are important angles from the point of view of the earth's magnetic field the declination and depth

 so declination angle between geographic north and horizontal component of magnetic field and dip or inclination is the angle between horizontal plane and the field direction

 so these two angles are important angles from the perspective of earth's magnetic field and they are important parts of the earth's field

so for example let me just give you some numbers here in new delhi declination is about one degree and seven minutes and inclination is about 44 degrees 37 minutes and pause towards positive east

so we can get a table of declination and deep at different positions on the earth and this these two are very important parts of the earth's magnetic field

so as you can see here we have essentially the earth is approximately dipolar field the orientation the magnetic field at any point on the surface of the earth is not horizontal it is tilted also the direction in which the north pole of the magnetic compass points is not exactly the geographic north pole

so its there is an angle and

so explorers have to correct the orientation of the magnetic compass needle to get the exact geographic north wherever they are on the earth surface and the both these angles change as you change the position on the earth surface in fact towards the north or south pole the the magnets will be pointing vertically and

so this is a very important aspect of earth magnetic field

so let me finish the lecture by just summarizing very briefly what we have discussed till now in magnetostatics we started with bio server law which gives me the magnetic field by a current carrying conductor then we discussed magnetic forces on moving charges and as an example we looked at a particle accelerator called the cyclotron then we discussed the field produced by current carrying conductors circular loop of coil at a straight conductor and obtained the ampere's law from there which is a very very important law we then introduce the concept of magnetic dipole moment looked at the torque on a magnetic dipole moment in external field potential energy of a magnetic dipole moment and from there we will discuss an example in terms of a moving coil galvanometer voltmeter ammeter and then we looked at different magnetic properties diamagnetic materials paramagnetic materials ferromagnetic materials and finally a small simple discussion on earth's magnetic field thank you you