good morning to all of you in our earlier lectures we had discussed about electrostatics i had introduced the concept of charge we had seen that charge produces an electric field surrounding in the surrounding area that electric field exerts a force on other charges

so if you have similar charges they are repulsed if they have opposite charges they are attracted

so we had seen the laws describing electrostatics we had also obtained gauss's law which helps us to obtain electric fields of charge distributions and we are discussed in detail the fields produced by different charge distributions now we move on to another topic which is magnetostatics

so if you have a charge at rest then the electrostatic force on the charge is because of an electric field when the starts when this charge starts to move then we find that other than this electric field there is another force on the charge which is called the magnetic force

so whenever a charge is in motion you can have electrostatic force because of an electric field and also a magnetic magnetic force because of another field which we define as the magnetic field

so this magnetic effects were discovered about 2500 year 500 years ago when they found that certain pieces of metals attracted other metal pieces and

so the field of magnetism was born and there have been lot of experiments by various people to discover laws governing the laws of magnetism and their relationship to electricity

so in this part of the module we will study things about magnetism magnetic fields how magnetic fields are generated what are the forces because of magnetic fields and how we can employ them for various applications

so before we start discussing magnetic effects i want to show you some demonstration simple demonstrations of magnetic effects which many of you may have seen somewhere in your in your during your studies okay

so we will start with some magnets which i am showing you here this is called a bar magnet and you can see here there is a on this on the upper side a certain n and on the other side is written s n corresponds to north and s corresponds to south that's called a bar magnet there is another magnet here which is called the horseshoe magnet n corresponds to north here and this corresponds to south here and you can have other shapes of magnets for example you have ring magnet here

so you can have all kinds of magnetic magnets now for example i will show you that if i bring this what is written as n close to n here then the there is force of repulsion as you can see here if i bring it to the point pole marked s it gets attracted

so just like electrostatic forces which we had seen as having both repulsive and attractive forces this n attracts s but if i bring n close to n it seems to repel this

so there is a repulsive force and an attractive force in these two cases you may have seen what we call as a magnetic compass here there is a magnetic compass here there is a magnet which is suspended on a on a rotating fulcrum and you can the magnet can rotate and as you can see it points along a certain direction irrespective of what i do to the mag to the to the system here when i rotate the needle always seems to point in one direction and this is the direction of the magnetic field produced by earth

so earth has its own magnetic field and this magnet gets aligned towards the magnetic field

so when we study magnetostatics we will study what are the forces and torques on magnets like this and how these magnets get aligned to different directions now in our early stages of development of electricity and magnetism electricity

and magnetism were considered to be two separate fields

so electricity corresponded to charges and magnetism was described as fields produced by magnets now it was in eighteen nineteen when hans christian oystered a danish physicist who was giving a lecture and during the lecture he suddenly discovered that magnetic fields are produced by currents currents have a magnetic field around them

so just to show you that experiment i am taking a small battery and i am taking a wire

so what i will do is i will connect the wire to the battery and i will place this near the compass magnetic compass and i will show you that this leads to a deflection of the compass

so let me hold the mag let me hold the wire close to the magnet here and if you see the if you see the magnetic see immediately as soon as i connect the magnetic needle rotates showing that there is a force magnetic force on the coil on the on the magnetic needle and that rotates

so this was an experiment which was performed by hans christian oyster to show that there is a very strong relationship between electricity and magnetism that currents produce magnetic fields

so what is actually happening as we see as we will see is a current propagating through this as soon as i connect the battery to this wire there is a current flowing through the wire that current generates a magnetic field that magnetic field then affects the needle here magnetic needle and the magnetic needle deflects

so there is a torque on the magnetic needle which then deflects

so this was the experiment which was performed by hans christian oyster long time ago and after that experiment people like ampere faraday henry and all these people did a lot of experiments and the entire field of magnetism got developed now we have introduced the concept of electric fields at that time and i had introduced a unit we know that electric fields are measured in volts per meter

so we need to have some unit of magnetic fields and as i will discuss when we start to look at the forces i will introduce a unit called tesla this tesla is a unit of magnetic field and it is named after a scientist nikola tesla and is a measure of the magnetic field tesla is a very huge unit

so usually we use a smaller unit called gauss which is 10 to the minus 4 tesla
so i will introduce this later on again and i want to show you that there is a meter here which actually is called the tesla meter which measures the magnetic field of any of it at any point

so i have now here two magnets which are extremely strong magnets as you can see here these are very strong magnets which are which attract each other and you can see here very strong magnets here and i want to show you what is the kind of magnetic fields that these magnets produce

so here is i put the magnet here and i this is a probe this probe at the tip of the probe there is a small crystal which actually measures the magnetic field now here is the here is a magnetic field unit on that on this you can see here there is a let me zero the magnetic field here approximately 0.
1

so m t corresponds to milli tesla and there is almost 0 mil tesla here
so if i bring this close to the magnet as you can see here the magnetic field increases it is measuring the magnetic field and then there is a negative sign here which corresponds to certain orientation of the magnetic field if i take the sensor on the other side you see there is a positive value of magnetic field here and you can see the magnetic fields are quite strong here something like a hundred up to about 100 mil tesla

so this magnets are very strong magnets and they produce typically hundreds of milli tesla earth has about 10 micro tesla magnetic field and these effects are very interesting from and they actually unify electricity and magnetism and incidentally there are naturally occurring living or natural living organisms which use magnetic fields for navigation for example there are bacteria called magnetotactic bacteria which have tiny magnetic crystals within them which help them to orient themselves along the direction of magnetic field and this they used to navigate into the earth because they want to go into regions with deficient oxygen contents similarly there are birds like pigeons which are understood to be using magnetic fields for the navigation for long distance migration birds use magnetic fields as one of the ah one of the sensing agents to direct themselves similarly there are ants which seem to use magnetic fields for navigation on the earth

so magnetic fields are very very important aspects and we will in this module study how the magnetic fields are generated by current canning conductors what are the forces generated by magnetic fields and what are the applications of magnetic forces now i must mention here that we had in electrostatics we had introduced the concept of electric field as a vector field

so we say that if you have a charge this charge produces a field surrounding itself which is called the electric field then if you place another charge here stationary charge then this electric field is exerting a force on the stationary charge either an attractive force or a repulsive force and that leads to the electrostatic force between these two charges similarly we will introduce the concept of magnetic fields

so if you have a current carrying conductor if you have a conductor which is carrying current then this current carrying conductor generates the magnetic field surrounding itself in the surrounding medium that magnetic field then can affect a magnet like a magnetic needle here or another bar magnet or another current canning conductor and it can apply forces which are called magnetic forces

so just like electric fields we will introduce the concept of magnetic field which is also another vector field and we will study various properties of magnetic fields okay

so we just saw some demonstrations of magnetic effects

so now i wish to discuss magnetic fields how magnetic fields are generated by current kinetic conductors what are the forces that are exerted on other objects

so remember in electrostatics we had defined the electrostatic force through an equation as follows

so electrostatic we had defined electric field as e is equal to f by q

so if you have a charge q stationary charge q then it is acted upon by a force f the force per unit charge we had defined as the electric field

so this is the electric field now because there are isolated charges in electrostatics we could define the electric field through an equation like this but we find that there are no such magnetic charges or there are no magnetic monopoles these are called no magnetic charges or no magnetic monopoles

so we would have to define magnetic field through another relationship and that is and actually as i mentioned last just a while ago that magnetic forces appear only on moving charges

so we need to define magnetic field through another mechanism

so suppose i take a charge which is moving in some direction then let me try to find out what are the forces acting on this charge

so suppose i have a region in this region i have a magnetic field for example a magnetic field produced by a magnet or a magnetic field produced by a current kinetic conductor and in that region i move a charge

so let me assume that all objects around it are neutral
so there are no electrostatic forces on this charge now we find that there is a force still acting on this charge because of its motion now what are the properties of these forces we find that as i change my direction of motion of the charge along one particular direction there is no magnetic force
so if the charge moves for example in this direction suppose i have a charge which is moving like this then there is no force magnetic force but if it moves like this there is a particular force acting on the charge
so there is one special direction i find along which if i move the charge there is no force there is no magnetic force if i move the charge along any other direction then there is a force acting on the charge and that force depends on
so suppose this is the charge this is the direction in which f was 0 0
so this is velocity if i move like this it may happen that that i will find there is a force acting on this and that 4 depends on this angle phi between the direction in which i have zero force and the direction of motion and i also find that the force is perpendicular to the direction of velocity of the charge and to this direction of zero force
so this force which i see acted upon by the on this moving charge is not only perpendicular to this velocity vector of the charge but also the to the direction in which i had found that the force was zero
so we defined a magnetic field p usually written as b along the direction in which
so the vector b is a vector which is oriented along the direction in which the charge found no force
so that's the direction of b vector
so this is the direction of b vector along which the charge there was no force on the charge and we defined
so we we then propagate suppose this direction i now propagate perpendicular to this direction this is perpendicular and i find i define the force i find the force as f is equal to
so i start i find certain force acting on this moving charge and as i mentioned this force is perpendicular to the velocity vector and also the b vector and
so i define a magnetic field magnitude of the magnetic field as b magnitude which is given as b is equal to mod of the force let me write a b subscript tell me the magnetic force divided by q times b
so the force acting on this moving charge is why
so i measure the force acting on this moving charge when the charge moves perpendicular to the direction in which i found the force had been zero
so in this direction i find the force and i the magnitude of the force divided by the charge which is moving multiplied by the velocity of this particle i define as the magnetic force
so in in terms of a vector vector field
so i i this is the vector magnetic magnetic field f b vector magnetic force is defined as q b cross b the magnetic force fb vector magnetic force fb is equal to q times v cross b q is the charge of the the charge which is moving moving b is the velocity vector of the charge and b is the corresponding magnetic field
so as you can see here if the velocity happens to be along the magnetic field v cross b becomes zero and the force becomes zero along other directions the force is finite
so if the angle between the velocity vector and the magnetic field is phi
so if i have a magnetic field pointing like this and if i move like this this is a velocity and this angle is phi then the force magnitude magnetic field force is equal to q v cross b magnitude which is equal to q b b sine phi
so at phi is equal to zero the force becomes zero at five is equal to ninety

degrees the force becomes maximum which is two v b and that is the way we define the magnetic field b

so magnetic field magnetic force depends on the angle between the velocity vector and this magnetic field and varies like this q v b sine sine phi

so let me take an example

so suppose i take a magnetic field

so let me take a coordinate axis x y z

so let me assume that is the direction of magnetic field and let me assume the the charge is moving in the x y plane at an angle phi with the magnetic field

so there is a plane i define the x y plane at the plane in which which contains the velocity vector and the magnetic field

so i can write the magnetic field v as b times j cap the velocity has two components it has a component along x axis and a component along y axis

so i have v sine phi i cap plus v cos pi j cap

so the velocity vector has a vector

so v sin phi into x i cap plus v cos phi j cap

so the magnitude of the force magnetic force is q v cross b which is equal to q v sin phi i plus v cos phi j cross b j which is equal to now q b b sin phi into i cross j which is nothing but ah q v b sine phi k cap j cross j is zero

so this component does not contribute to the force the only component that contributes to the force is the component along i cap

so q v b sine phi i cap cross j cap which is k crab

so this force as you can see here is acting perpendicular to both the velocity vector and the magnetic field and is oriented in a direction which is actually the cross product of v and b the magnitude of the force depends on the angle phi and of course the magnitude of the force also depends on the charge and the velocity also notice that depending on the sign of the charge the force is either positive or negative

so if you have a positive charge the the force along k in this equation if the charge q is positive the force is on k cap if the charge is negative its along minus k cap now what is k cap k cap is this direction

so one has to use what is called as the right handed rule for calculating the direction of the force on this moving charge

so the charge velocity is like this the magnetic field is like this

so if i i use the right handed screw right handed rule

so i take my i take my hand from i take my right hand with the four fingers pointing along the velocity vector and move it towards the magnetic field direction and the direction of the thumb tells me the force acting on a positive charge

so i take a movement from the velocity vector to the magnetic field the directional thumb tells me what is the direction of the force now this is called the right-handed rule and this is also sometimes referred to as the right-handed screw rule for example here i have taken a screw there is a nut here and there is a screw here

so if i look here if i rotate in this direction if i rotate

so let me take a screw like this if i rotate in this direction the screw is moving forward if i rotate in the reverse direction the screw is moving backward

so this this rotation in this direction gives me a force like this

so if i take the screw like this and i rotate the the screw from the velocity vector to the magnetic field the direction of motion of the screw gives me the direction of the force

so this is called the right handed screw rule

so i can either think in terms of right handed screw rule or in terms of a right handed rule

so which means that i show my four fingers along the velocity vector rotate the hand towards the magnetic field and the direction of the thumb shows me the direction of the force on a positive charge the force on the negative charge will be exactly opposite

so the force is perpendicular to the magnetic field this is very different from what you saw in electrostatics where the force was along the direction of the electric field

so let me compare the two forces the electrostatic force and the magnetostatic forces

so we can see here

so let me take an example

so let me take a charge of 1 micro coulomb which is equal to 10 to the minus 6 coulomb a magnetic field of 10 milli tesla mill tesla and let me assume the charge is moving at a velocity of 10 meter per second

so the force is equal to and let me assume that the velocity is perpendicular

so this is the magnetic field and the charge moving like this that's 90 degrees

so q v b which is equal to 10 to the minus 6 coulomb into 10 meters per second into 10 milli tesla which is equal to 10 to the minus 7 newton that's the force acting on the charge

so i have if i have 10 micro coulomb which is moving in this direction here positive charge then the direction of the force as you can see is v cross b

so i take my right hand from the direction of v to b and the thumb is pointing downward

so if the charge is positive the charge will be pushed downward because of the magnetic force

so that's an example which tells me now i need to define the unit of this magnetic field

so s i unit as i mentioned before it is tesla this is after the scientist nicola tesla eighteen fifty seven to nineteen forty three

so one tesla is ah

so i have to define the force in terms of magnetic field the magnetic field in terms of force

so one newton by one coulomb into one meter per second which is also one newton by one coulomb per second into one meter and coulomb per second is current

so this is nothing but newtons per ampere meter coulomb per second is an ampere that is the unit of current

so one tesla is actually one newton am per ampere meter and that is the unit of magnetic field tesla and as i mentioned to you tesla is a very large unit

so we also define a much smaller unit called gauss

so one gauss is equal to 10 to the minus 4 tesla

so that gives you the unit of magnetic field

so let me give you some indication of the kind of magnetic fields found in various situations

so if you go to the surface of a neutron star the field is 100 million tesla ah in one of my early lectures i had mentioned about trains which are super fast called magnetic levitation trains in those trains we use magnetic fields of the order of five tesla

so these are trains which are floating because of magnetic forces and they can run at very high speeds magnetic resonance imaging is a very important instrument in medical field and this uses a strong magnetic field and the typical magnetic field is about one tesla near a small bar magnet which we saw a little while ago

so you the magnetic field is about 10 milli tesla the earth's magnetic field is about 10 to the minus 5 tesla and there is a magnetic field in the interstellar

space and that magnetic field is about 10 to the minus 10 tesla
 so you see a very large large range of magnetic fields right from 10 to the minus 10 tesla in the interstellar space to near the surface of a star like a neutron star where the magnetic fields can raise to 100 million teslas
 so it's a very large range of magnetic fields and
 so you can generate very very strong magnetic fields using some of these concept that we will discuss
 so we now introduce the law which will tell me what is the magnetic field produced by a current kind of conductor this law is called bio server law named after two scientists john baptist bio 1774 to 1862 and felix savard seventeen ninety one to eighteen forty one
 so they introduced this law which will help us to find out what is the magnetic field generated by a current kinetic conductor now please remember we have discussed in electrostatics that when you have a charge which is stationary it produces a field which we call the electrostatic field and that field then affects any other stationary charge
 so this is electrostatics because the charges are stationary now we do not have magnetic charges
 so we only have currents and
 so in a similar fashion we find that a steady current a current which is constant in time does not change with time will produce a magnetostatic field that is the magnetic field which will not change with time now just like electric field e being a vector field which is a function of both position and time magnetic field is also a vector field which is a function of position and time and the magnetic field which is produced by a stitch with by a steady current that means i take a wire and i pass a constant current to the wire this constant current will generate a time independent magnetic field in the surrounding space that magnetic field can then affect other magnets or other current carrying conductors or other charges and as we have seen if there is a charge near a current kinetic conductor and if the charge is not moving then there is no magnetic force on the charge even even if there is a magnetic field because velocity is zero
 so we will introduce this bio several law
 so we consider a let me consider a wire which is carrying current
 so let me consider a wire like this which is carrying current i
 so i want to find out what is the magnetic field at some point p
 so for this what i do is i take a small element of length here d l d l vector which is along the direction of the wire and let me draw the this this line to be along this direction tangent to the wire at that point and let me join this
 so this is r vector and let me call this theta
 so this current canning conductor means what there are charges flowing through the through the conductor and as we have seen a moving charge will produce a magnetic field
 so this moving charge in this which is current here produces magnetic field
 so we will define the magnetic field produced at the point p due to the small current element as given by mu zero by four pi i d l cross r by r cube
 so the magnetic force magnetic field produced by a small current element d l vector is given by i mu naught by four pi i d l cross r by r cube r is the distance from here this is not a unit vector
 so i if i want to write in terms of unit vectors i must write like this mu zero by four pi i d l cross r cap by r square
 so just like the electrostatic field this is also an inverse square law one by r square and it depends it is a vector its a vector field here and it depends on this quantity d l cross r

so a small current element dl produces the magnetic field which is oriented along the vector direction of d l cross r and this quantity here this is introduced as a constant of proportionality

so mu zero by four pi is a constant of proportionality and mu 0 is called permeability of free space we are introduced epsilon zero in electrostatics permittivity of free space here we introduce another quantity called mu zero which is the permeability free space and this quantity has a value mu zero by four pi this mu naught by four pi is defined to be ten to the minus seven tesla meter per ampere

so that's by definition the constant mu zero by four pi is ten to the minus seven test meter per ampere and mu zero is a constant proportionality

so just like a stationary charge produces an electric field surround in the surrounding space a current carrying conductor produces a magnetic field and this small element of current dl carrying a current i

so i is the current flowing through this wire and

so this small element of current is i times dl vector that current element produces a magnetic field here db vector which is mu naught by 4 pi the current times d l cross r by r cube

so just like a electrostatic fold field we have now defined a magnetic study field in terms of current and in terms of the small current element now i want to make a comparison between the electric and magnetic fields as you can as we have seen here now

so comparison let me put a comparison here both e and b fields are long range

so they have they can act at very large distances the electric and magnetic fields they are long range forces both of them decrease as one by r square both of them satisfy an inverse square law both obey principle of superposition which means that if you have two current elements producing two magnetic fields at a point then the total magnetic field in the presence of both current elements is the sum of the magnetic fields produced by each individual current element e field is produced by a scalar charge which is the charge while b field is produced by a current element i d l a vector e is along the line joining the charge and the point p while b is perpendicular to the plane containing r and ideal also the magnetic field b depends on angle between i d l and r vector

so these are some points which you may remember both electric and magnetic fields are long range fields

so they have effects over very long distances both decreases 1 by r square both of them are inverse square law both the fields obey principle of superposition this is very useful to calculate magnetic fields produced by different current distributions electric field is produced by a scalar quantity which is the charge while the magnetic field is produced by current element which is a vector idl vector the electric field is along the line joining the charge and the point p where you are calculating the electric field while the magnetic field is perpendicular to the plane containing the r vector and the current element ideal and finally the magnetic field depends also on the angle between the current element idl and r vector now incidentally we may we may note that epsilon zero mu zero can be written as four pi epsilon zero into mu zero by four pi four pi epsilon zero we have seen is one by approximately one by nine internal power nine and mu zero by four pi is ten to the minus seven

so this is equal to one by nine into ten to the power sixteen which is equal to one by three to the power eight square and this is three ten per eight meter per second is nothing but velocity of light in free space

so this is nothing but one by c square

so its important to remember that c is actually equal to one by square root of epsilon zero mu zero the velocity line in free space is related to the electric

permittivity permittivity of free space and permeability of free space through this equation and thats very very important equation we will come back to this later when we discuss maxwell's equations ok now i want to calculate magnetic fields of current distributions
 so let me take the following example i want to calculate magnetic field on the axis of a circular loop of current
 so i have a i have a circular loop which is carrying current ok
 so let me call this axis this is x axis let me call this x axis this is y axis and this z axis
 so i orient the axis at the center of the current loop
 so that is a current loop which is carrying a current and using bio saber law i want to calculate what is the magnetic field along the axis of this current loop we will be able to find this through integration of the bio server law for points of access it is not easy to calculate and we will restrict ourselves to calculating the magnetic field along the axis of this circular coil is a certain loop of current
 so how do we calculate
 so i take some point here where i want to calculate let me call this point p
 so what i need to do is i need to calculate the magnetic field produced at this point by different current elements this element produces a magnetic field here this current element will produce a magnetic field here this current element will produce magnetic field here
 so i take all current elements in the circular loop calculate the corresponding magnetic fields here and add them vectorially please remember magnetic field is a vector field
 so when i add the magnetic fields i must be careful in adding them vectorially
 so i calculate the magnetic field from all the small small elements of currents and use the superposition principle to sum them up factorially to calculate the total magnetic field now remember we had we had this biostate law d b is equal to mu naught by four pi i d l cross r by r cube
 so if i want to calculate the current due to this current element i draw a line like this this distance is r and this is idl this small element is ideal this is the magnetic this is the r vector this r vector
 so remember this magnetic field at this point because of this current element it is perpendicular to both the dl and the r vector and it is given by this equation now please notice here that d l and r are always perpendicular because of the orientation of because i am choosing myself to be along the axis of this circular loop
 so d l cross r magnitude is always equal to d l r or is the distance from here to here and the direction of magnetic field is perpendicular to both
 so let me draw another figure here to to show you the orientation of magnetic field
 so let me take the x z plane
 so remember the loop the current loop is along the direction
 so the current is coming out from here i drop a point here and the current is going back into this thats the tip of the arrow that's the back of the arrow
 so the current is coming out of the paper here and current is going into the paper here
 so that is my point p where i am to calculate the magnetic field
 so when i because of this element
 so this is r vector d l vector
 so d l cross r
 so d l vector is perpendicular to the page
 so the vector perpendicular to d l will be in the plane of the paper and that

vector has to be also perpendicular to r vector
 so the magnetic field produced by this will be now i must use the right handed screw rule
 so the current is going up i mean coming out of the paper and i rotate towards r and i get the magnetic field direction as this this is the magnetic field produced by this current element at this point this is perpendicular to the current element which is coming out of the paper because b vector lies in this plane it is also perpendicular to this vector this r vector direction
 so if i call this theta
 so b vector now has both components along the x axis and the z axis in the exact plane now it is interesting to note because the the problem is very symmetric
 so it is interesting to note that if i look at the current element which is exactly diametrically opposite on the other side
 so for example in this figure if i am looking at this current element i look at the current element if i look at this current element there is another color element here for a current element here there is another element on the other side
 so what i do is for a current element here this is the magnetic field for this current element which is now current is going inside the magnetic field happens to be exactly the same magnitude but in this direction because this current is going inside the paper and the r vector is here corresponding to this element the magnetic field happens to be in this direction that angle is also theta the current element dl and the distance are exactly equal for both cases
 so the magnitude of the magnetic fields at both cases are the same
 so let me call this sort of db and db
 so this is the db current magnetic field produced by this small current element dl here it l this is the magnetic field produced by another current element idl here and what you notice is they subtend the same angle with a z axis and they are oriented like this
 so immediately i can see that this particular magnetic field has a positive component along x this magnetic field has a negative component along x having the same magnitude but oppositely directed
 so what you see is the x components of both the magnetic field produced by this current element and this current element will cancel each other and the z components will add to each other
 so please just see this problem because of symmetry i find because i am looking at the magnetic field along the axis of the circular loop this current element produces a magnetic field oriented like this in this direction oblique to the in the exact plane this current element produces the magnetic field in this direction the angles theta are exactly the same because all the as you can see from the triangle here and because of this the x component of this magnetic field produced by this is exactly equal and opposite to the x component of magnetic field produced by this element current element
 so what you will find is if you take the circular loop for every current element there is exactly another current element in the opposite diametrically opposite point which will produce another magnetic field whose x component will cancel
 so similarly here this component will cancel with this component the
 so all comp all the components of magnetic fields perpendicular to z axis will cancel each other
 so this one and this one will produce magnetic fields whose components perpendicular to z axis will cancel similarly this one and this one will produce magnetic fields whose components perpendicular z axis will cancel and

so on

so all that will happen is all the components along the z axis will add to each other and the components perpendicular z axis will cancel from each other

so all i need to do is first thing i notice is the total magnetic field produced by this circular loop must be along the z axis and i can calculate the magnitude of the ah magnetic field now

so let me write this as d b z is equal to

so i had written this equation here mu naught by four pi

so i have mu naught by four pi i d l r by r cube was the d l r d l cross r is d l times r by r cube and i was looking i am looking at the z component which is cos theta

so this magnitude this is the total magnitude of the magnetic field and his its z component is cos theta this the x components cancel each other

so that is the magnetic field here and cos theta i can calculate

so if this is the radius of the coil and this distance is r

so cos theta

so this angle is theta

so notice that this line is perpendicular to this line and this line is perpendicular to this line

so this angle is also theta this r vector is perpendicular to this the magnetic field is perpendicular r vector and this line is perpendicular to this line

so that angle is theta

so cos theta is nothing but capital r by small r

so d b z becomes mu naught i by four pi r square d l into r by r

so i can write the magnetic field not i r by four pi r cube two d l and if you notice

so if this distance is z then r square is equal to r square plus z square

so i can write i can use this formula in this equation and write this as mu naught i r by 4 pi into r square plus z square raised to the power 3 by 2 d r

so that is the magnetic field produced by a small current element dl suppose suppose this element now i must integrate over all the elements of the current which is along the circle

so i will integrate this to get the total magnetic field b z is equal to mu naught i r by four pi r square plus z square raised to three by two integral d l and integral d l is nothing but the circumference which is two pi r r by four pi r square plus z square c by two into two pi r

so thus this gives me mu naught i r square by two times z square plus r square theta

so i can write the total magnetic field

so if this is my current loop this z axis x y

so the total magnetic field along the axis at a point on the axis at a distance z from here is equal to mu naught i r square by two times z square plus r square three by two k cap ok

so we can see we can actually calculate the magnetic field at any point along the axis and it depends on the distance from the ah from the plane of the circular loop to this equation

so if i were to plot b magnitude versus z what you will find is ah as you can see here there is z square plus r square in the denominator the maximum magnetic field will appear when z is equal to zero and as that increases to either positive or negative side the magnetic field will decrease and

so you will get the magnetic field going like this

so this is the peak of the magnetic field which is given by

so ah magnetic field at the center of the loop magnetic field b is equal to mu naught i by

so this is my current carrying conductor loop here
so at this point the magnetic field is pointing like this
so as you can see here again we have the right handed screw rule here
so if i if i take my if i take my nut like this
so if i if i rotate if i rotate like this in the in the direction of the current i see the screw is moving towards me and
so that is the direction of the magnetic field
so the right handed screw again rule gives me the directional magnetic field
so if i put my fingers along the direction of the current i get the directional magnetic field
so magnetic field is pointing along the k direction here which is given by this now
so this is for a single loop if you have multiple loops you can actually calculate
so if you have n loops closely bound the total magnetic field will be at the center will be mu naught and i ok
so you can actually increase the magnetic field by changing a larger putting a larger number of loops in the in the coil and you can get a strong magnetic field
so let me take one calculate one example
so let me take a loop of radius 20 centimeters ah number of turns is hundred and the current i pass is five amperes
so the magnitude of magnetic field at the center is given by mu naught and i by two r which is equal to four pi ten to the minus seven into hundred into five divided by two times point two which is approximately 1.
57 milli tesla
so you can see if you have a 100 loop coil with 20 centimeter radius you will get about 1.
6 milli tesla at the center of the coil and as you move away from the center on either side the magnetic field will decrease and notice also that the directional magnetic field
so if in the in the slope here here the magnetic field is like this and the magnetic field is pointing away from the loop here
so the current is flowing like this now let me leave a small problem to you calculate the magnetic field at the center of a circular arc of wire of radius r carrying current i
so you have current carrying circular arc that's the center and let me assume this angle is phi
so that's an arc
so this is just the arc instead of a circle i have an arc carrying a current
so what is the magnetic field here please calculate this thank you very much you