

good morning to all of you we will continue with our discussion on electromagnetic induction remember in the last class we have discussed faraday's laws of electromagnetic induction we discussed that if you change the magnetic flux through a closed loop then there is an induced emf and if there is a conductor in that loop then the induced emf generates a current and we also introduce lense's law which says that the induced current is

so as to oppose any change in the magnetic flux

so if you have a coil or a loop of conductor in which you increase the magnetic flux with time then the induced current is

so as to oppose this change that means it will produce a current in such a fashion that its magnetic field is opposing this change

so it will be oppositely directed to the external magnetic field similarly if you reduce the magnetic flux then it will induce a current which will oppose the change that means oppose this reduction in magnetic flux and will add to the existing magnetic flux and

so this is a very important law in electromagnetism and is as i mentioned in the last lecture has a large number of applications we also actually i had shown right in the beginning of discussion of magnetostatics a very interesting experiment in which i showed that the induced emf can generate eddy currents in bulk conductors and those eddy currents can oppose the motion of these objects and also i showed you that there is electromagnetic levitation

so i had a solenoid with a aluminium block on top of the solenoid and i as i increase my current the aluminum cylinder actually rose up and that is a case of an eddy current i want to discuss and i want to show you some more very interesting experiments on eddy currents and ah and this is the experiment

so what i have what i have got is two tubes of almost equal length one is a pvc tube this is a white one and the other one is a copper tube and here is a very strong magnet this is not magnetic this is not magnetic both of them are non magnetic and what i am going to do is the following i want to drop this magnet through these two tubes now if i drop a magnet outside its a mass which is being extracted by the gravitation and

so it falls with a certain acceleration of course there is a viscous force but that viscous force is very small in the small distance of propagation now i if i drop it in this plastic tube except for the air coverage by the plastic tube it is going to fall at almost the acceleration due to gravity and i want to see what happens when i drop this in either the plastic tube or the copper tube

so let me show you this okay

so i am going to drop the magnet in the plastic tube as you can see here it takes a finite time to come down it is quite small because the length is very small again let me drop it takes very little time now i want to drop the same magnet in the copper tube here i am dropping it and you see how much time it takes it takes much longer to come out of the copper tube compared to the plastic tube what is actually happening is this is a magnet a very strong magnet and as the magnet enters the copper tube copper is a good conductor of electricity this moving magnet changes the magnetic flux across different cross sections of the copper tube and because of faraday's law an induced emf is generated in this copper tube that induced emf generates current because this is a conductor and those currents oppose the motion of the magnet

so effectively what is happening is there is a force generated by the induced emf which is opposing the motion of the magnet and as the magnet is accelerating downwards the induced emf is generating a force upwards the induced currents are generating a force upwards which means its like a viscous force its like dragging its its not allowing the magnet to fall fast enough and as you can see here if i drop it at this instant of time it takes consider considerable

time to fall out compared to the plastic tube

so let me drop once more in the plastic tube there it is and then there is a copper tube now its a considerable time and that time difference is primarily because of induced currents generated here this being a plastic tube there is no current because this is not a good conductor there is no there is electric field generated please remember as the flux changes as the magnetic field changes there is an electric field generated but there is no current in this but there is a current in this which is opposing the change and which is opposing the movement of the magnet through the tube this is a very very interesting example or a very nice demonstration of induced emfs and all of you can also do the same experiment provided you get a strong magnet and a copper tube sufficiently thick

so that its conductive its a it can conduct and create good currents i want to show you ah another experiment with a longer property just to impress you the time it takes for the magnet to fall through a very long copper tube and i will now just show you a much longer tube than this one with a longer cross section with a bigger cross section and a longer copper tube

so i want to show you that

so here is a copper tube with a long copper tube which is about one and a half meters long and you can see this is the top of the tube here and you can see at the bottom i placed a piece of paper just to show you when the magnet falls

so this is a long copper tube and it generates significant amount of eddy currents for the magnet to fall and resist the motion of the magnet itself through the copper tube

so this is a very very interesting demonstration of generation of eddy currents and i also want to show you another experiment using the same copper tube where i will show you that the movement of a pendulum which is actually a magnet in front of the copper tube induces a lot of back resistance and this and and slows down the the motion of the pendulum now here is a the same magnet now suspended from a string in the form of a pendulum and if i give it an oscillation you can see the it oscillates with a certain frequency and it has very little damping it oscillates significantly fast and because of air resistance there is some kind of a slowing down but it is oscillating with almost same amplitude for a longer time now i what i want to show you is i bring this copper tube below this magnet and as you can see immediately the magne the magnet is slowed down because of any current generated in this copper tube let me show you again i make the magnet oscillate and if i bring the copper tube below the magnet the magnet actually generates any currents in the copper tube those nd currents are such as to the oppose the motion of the magnet which is the pendulum and

so the pendulum stops

so if i do in this direction for example it also generates a recurrence but eddy currents are much lower and it takes a little longer to stop compared to this direction it is very quickly damped out and these two these demonstrations which i try to show you today are demonstrations showing effects of eddy currents and as i mentioned in the last lecture eddy currents have a lot of applications in various branches of science and technology and of course they also have problems because in transformer course eddy currents are responsible for heating of the course and in that process the energy is lost from the system

so eddy currents have applications or also have problems in certain situations so these were two very interesting demonstrations of eddy currents and i want to continue with my lecture ok

so we just now saw some very interesting demonstrations of eddy currents generated by changing magnetic flux through a copper conductor and these eddy currents are responsible for the experiment which i showed you the slowing down of the magnet as its dropped as it accelerates towards the earth and these are

very interesting demonstrations of the currents and they are also used in braking systems where eddy currents actually oppose the motion of the magnet and they can be used for slowing down a vehicle for example

so let us continue with our discussion in the last lecture I had also introduced the concept of mutual inductance

so if you have two coils two arbitrary loops for example if this is carrying a current i_1 and it produces magnetic field then this particular circuit will enclose a certain flux magnetic flux generated by this current and we had defined the flux in the second coil as $M_{21} i_1$ and this is the mutual inductance

so when two conductor conducting loops lie close to each other a current propagating in one of the loops induces flux through the second loop and that flux is proportional to the current generated in the first loop and that proportionality constant is called the mutual inductance in fact I also showed you that M_{21} is equal to M_{12}

so if I pass a current through the second the upper coil the amount of flux that is passing through the lower coil is also proportional to the current passing through the upper coil and the proportionality constant happens to be the same and I had used this property in discussing one very interesting example where it is much easier to calculate one of the mutual inductances as compared to the other after this I also introduced the concept of self inductance

so if you have a coil like a solenoid passing a current through the solenoid creates a magnetic field

so each loop of the solenoid is also enclosing the magnetic flux generated by the solenoid

so there is a flux passing through each loop of the solenoid

so through the entire solenoid now encloses is a flux generated by the current passing through the same solenoid and that flux is referred to that gives me a self inductance

so if I had a like last time if I had a solenoid here and if I pass a current through the solenoid then the flux through the solenoid is equal to some $L i$ and this L is called self inductance and

so self inductance is a flux enclosed by a circuit because of a current passing through the same circuit mutual inductance is between two different circuits or two different loops of current and this flux is it is very important because whenever the current changes the flux enclosed by the loop will change for example if I change the current in the solenoid the flux enclosed by the solenoid will change a changing flux induces an emf and that emf will oppose the change in current

so when you look at self inductance it induces what is called as back emf

so if you try to change the current in this in the solenoid then the changing current induces the changing magnetic flux a changing magnetic flux induces an emf and according to Lenz's law that induced emf or a current is supposed to oppose the change in the current

so when you try to increase the current there is an opposing force which is forcing you to slow down

so this is called the back emf and we have seen some examples in the last class also remember the unit for inductance is henry one henry is equal to one tesla meter square by ampere its an SI unit and I want to discuss one more example of a toroid

so we are looking at a toroid remember in one of the earlier classes we had discussed the magnetic field of a toroid

so toroid consists of a structure like this with loops like this for example surrounding the entire toroid closely bound loops

so current comes in from here and goes out from here
so let me assume that this radius is small r and the current passing through is i

so mean radius is equal to small r and area of cross section that is this area this area is a the area of cross section not the cross section of the entire toroid but the cross section of the the cross section of the toroid here

so now to calculate the inductance i must know the flux

so to calculate the flux i must know the magnetic field

so if the area of cross section if the if the dimension of the toroid is small compared to the average diameter i can assume that the unit the magnetic field is uniform uniform within the thoroid and by symmetry as we have discussed before the magnetic field must be in this direction

so the ah magnetic field i can calculate by using ampere's law

so i take a a loop like this

so the ampere's law is $\oint \mathbf{b} \cdot d\mathbf{l}$ is equal to μ_0 times i enclosed b is the same all across the circumference of the circle and it is pointed along the $d\mathbf{l}$ vector

so $d\mathbf{l}$ vector at every point is like this here is like this

so b and $d\mathbf{l}$ are parallel

so $b \cdot d\mathbf{l}$ is b times $d\mathbf{l}$ and b is the same all across the circumference of the solenoid of the toroid

so i can take b out and integral real becomes simply $2\pi r$

so $2\pi r$ into b is equal to μ_0 naught times now what is i n closed remember if there are total number of turns is n t there are n d turns in this toroid then the total current enclosed is n t times i

so each of this loop encloses a current i there are n t such loops total number of loops

so the total current enclosed is n t times i

so magnetic field is equal to μ_0 naught n t by $2\pi r$ into i

so i am going to assume this magnetic field is uniform ah across the cross section of the thyroid and once having calculated the magnetic field i can calculate the magnetic flux through each turn is equal to the magnetic field into area which is equal to μ_0 naught and t by $2\pi r$ into a into i

so this area is the area of each loop of the toroid the magnetic field is b

so the total magnetic flux linking all the n t turns of the toroid are obtained by multiplying this by n t

so you will get μ_0 naught and t square a by $2\pi r$ e two i

so the total magnetic flux is given by μ_0 naught n t square a by $2\pi r$ because this is the flux enclosed by each loop of the toroid and there are n t loops in the toroid

so each of the loops of the toroid encloses the flux magnetic field into area and there are n t number of loops

so the total flux enclosed is this and this gives me a self inductance as because this i will write as l times i and

so self inductance l is equal to μ_0 naught and t square a by $2\pi r$

so that is a self inductance of a toroid i can put some numbers and calculate

so let me put in some numbers

so let me write here self inductance of the toroid is μ_0 naught n t square a by $2\pi r$

so as an example let me take the total number of turns as two hundred an area of five centimeter square which is five into ten to the minus four meter square an average radius of 10 centimeters which is 0.

1 meters and

so the inductance is $4\pi \cdot 10^{-7} \cdot 4 \cdot 10^{-4}$ and

πr^2 into area is 5×10^{-4} divided by 2π times r which is point one and if you substitute all this you will get forty times ten to the minus six henry which is equal to forty micro henry ten raise to minus six is a micro so the self inductance is 40 micro henry of the toroid now if i take the toroid and change the current in the toroid

so if i change i through the toroid and if $\frac{di}{dt}$ the rate of change of current is equal to 5 amperes in 10 micro seconds which is 5 into 10^{-10} to the power 5 amperes per second that is the rate at which i am changing the current the induced emf minus $L \frac{di}{dt}$ which is equal to minus forty micro henry into five into ten two five five which is equal to minus twenty volts

so you will generate an induced emf of 20 volts across the thyroid if you change the current at the rate of 5 amperes and 10 microseconds and that gives you induced emf and depending on the resistance of the toroid this induced emf will generate a current through the to the toroid and that will be the one connect one can calculate the kind of ah current that is generated in the thyroid once i know the resistance of the coil of the toroid ok

so all this discussion has given me the concept of self inductance and mutual inductance now remember in electrostatics when we were discussing ah electrostatics we discussed also the energy that is present in electrostatic fields

so i want to use the similar argument to calculate to show you that in magnetic fields there is energy stored energy stored in the form of magnetic fields and to show this let me take the example of a solenoid

so let me calculate energy in magnetic fields

so i want to calculate what is the energy stored in magnetic fields

so for this let me consider a solenoid a coil with self inductance L

so i consider coil for example solenoid with self inductance L when the current in the coil changes with time for current changing with time i will get an induced emf minus $L \frac{di}{dt}$ L times i is the flux L is the self inductance L times i is the flux

so minus $L \frac{di}{dt}$ which is minus $\frac{d\phi}{dt}$ is nothing but induced emf and

so this induced emf as i have been discussing the minus sign includes is the fact that it is trying to oppose any changes in the magnetic flux for example you have the current when you try to increase the current there is an opposition to the increasing current when you try to decrease the current there is an opposition to decrease in current and

so whenever i try to increase the current there is an opposition to my increasing the current which means i must do extra work to increase the current against the opposing forces and

so when i am increasing the current i am doing work on the system to increase the current and that work which i am doing actually finally gets stored in the form of a magnetic field within the solenoid to show this

so what is emf emf is nothing but the work done in carrying a unit charge across the across the complete cycle circle across the complete circuit

so e is equal to work done in carrying in moving unit charge through the circuit

so because it is a back emf ah through the circuit because it is a back emf i must move it against this emf and

so the work i must do is given by minus e work done by the external agent i must work against this induced emf and

so i must do a work of moving a unit charge which is minus e now what is current current is nothing but the amount of charge moving per unit time if i have a current i the amount of charge that i am moving across the circuit per

unit time is nothing but current

so i represents current i represents total charge crossing the circuit per unit time

so if i neglect resistance or resistive heating the work done per unit time will be equal to i call this dW by dt the work done per unit time is minus e times i please note work done in moving one unit charge through the circuit is minus e i represents the amount of charge flowing crossing per unit time

so i must move i unit i charges per unit time through the circuit and for moving each charge i am doing a work minus e

so the amount of work that i am doing per unit time against the induced emf is essentially minus e times i which is nothing but minus i minus $l \frac{di}{dt}$ by dt is so this is plus

so e is minus $l \frac{di}{dt}$ with a minus sign here it becomes $l \frac{di}{dt}$

so i can calculate the total work done in increasing the current from zero to i will be equal to W is equal to ah $l \int_0^i i \, di$ zero to i which is equal to half $l i^2$

so this is the ah work done per unit time and if i have to increase the current from 0 to i the work that i need to do is integral of this and that becomes simply W is equal to l times dt cancels off and i get $i \, di$ and that is half $l i^2$

so this is the work that i need to do to increase the current from 0 to i and this what that i am doing is actually stored in the form of a magnetic field inside the inductor

so this particular solenoid or the circuit actually if i increase the current from 0 to i i have done some work and that work is stored in the form of a current processing through the solenoid or the coil or the magnetic field

so i want to interpret this in terms of magnetic fields

so this is in general this is for not just for solenoid for any inductance any circuit containing a self inductance l there is a current stored in the self inductance and that is simply half $l i^2$

so i want to take an example here in that example i want to take a solenoid a closely bound solenoid

so closely bound and very long

so i will assume that the magnetic field is uniform uniform within the solenoid and a zero outside as we have seen before in a solenoid closely bound solenoid the magnetic flux the magnetic field is ah means within the solenoid is uniform and what is the magnetic field we have already calculated b is equal to $\mu_0 n i$ where n is the number of turns per unit length and the current passing through is i now in the earlier lecture i had actually calculated the inductance of the solenoid and inductance came out to be self inductance came out to be l is equal to $\mu_0 n^2 \pi r^2 l$ self inductance of a length l of the solenoid we had calculated is $\mu_0 n^2 \pi r^2 l$

so what is the energy stored energy stored in the solenoid half $l i^2$ which is equal to half $\mu_0 n^2 \pi r^2 l i^2$ here r is the radius of the solenoid

so i can write this as half $\mu_0 n^2 i^2 \pi r^2 l$ now let me write this in a slightly different form

so i write this as one by two $\mu_0 n^2 i^2 \pi r^2 l$

so i multiply and divide by $\mu_0 n$ and i write this as one by two $\mu_0 n^2 i^2 \pi r^2 l$ now what is $\mu_0 n i$ i just now saw $\mu_0 n i$ is nothing but the magnetic field within the solenoid and what is $\pi r^2 l$ $\pi r^2 l$ is the area of the solenoid multiplied by the length of the solenoid is the volume of the solenoid

so this is the volume

so this is the volume of the solenoid and this is the magnetic field

so i can write i can say that this solenoid has

so much energy stored in the magnetic field this is the magnetic field

so i i write let me write this as one by two mu naught b square into volume
this is b of the solenoid and this is the volume of the solenoid

so i can write this energy stored which i have calculated as half l i square
has one by two b one by two mu naught b square into volume

so what does this give me it gives me that this must be the energy density of
the magnetic field

so i can i get an expression for the energy density which is the energy per
unit area sorry per unit volume u b is equal to half one by two mu naught b
square that's very important expression

so what i have what i have seen is i can interpret the energy that i have spent
or the work which i have done in charging up the circuit or a solenoid in this
example to increase the current from zero to i was half l i square and i wrote
that half l i square in a slightly different form in a form which looks like
this is one by two mu naught b square b is the magnetic field within the
solenoid into volume of the solenoid

so i can interpret that the energy that is being stored in the solenoid is in
the form of a magnetic field and that magnetic field has a energy density which
is energy per unit volume of one by two mu naught b square and

so this is a very very important ah relationship now although i have derived
this for a solenoid this is a very general relationship that the if you have a
magnetic field b at any point it creates an energy density of b square by two mu
naught and this is very similar to what we have done for electrostatics
electrostatic energy stored per unit volume u e was one by two epsilon zero e
square that is the energy tends to be electrostatic fields that is energy
density of the magnetic field and their civil relationship epsilon zero gets
replaced by one by mu zero here

so electric fields and magnetic field store energy and i had obtained this by
taking an example of a capacitance parallel plate capacitor and here i have done
this using a an example of a solenoid but please remember these expressions are
very general they are not restricted to parallel plate capacitor or a solenoid
and although i have not obtained this very generally these equations are valid
in general

so whenever you have an electric field and a magnetic field they will

so you can store energy in the form of fields electric and magnetic fields

so let me calculate let me look at an example

so suppose i have a magnetic field b of one tesla then the energy density which
is equal to one by two mu naught b square which is equal to one by two times
four pi ten to the minus seven into one which is equal to one by eight pi ten to
the power seven joules per meter cube

so that's the energy stored in this magnetic field if you have one tesla
magnetic field at a certain point there is a magnetic field energy density of 1
by 8 pi 10 to the power 10 per 7 joules per meter cube in that volume

so if i look at a solenoid for example if i take a solenoid of n is equal to
thousand turns per meter and if i pass the current i is equal to one ampere
through the solenoid the magnetic field is mu naught n i four pi ten to the
minus seven into one thousand into one which is equal to 4 pi 10 to the minus 3
minus 4 tesla and the energy density u b one by two mu naught b square

so i can again write this as one by two mu naught ah into mu naught square n
square i square which is equal to mu naught n square i square by two and i can
substitute this as four pi ten to the minus seven into ten to the power six into

one divided by two and that is equal to two pi into ten to the minus one joules per meter cube point two joules per meter cube is the energy density of the solenoid you can interpret this is the passing current which is storing the energy or the magnetic field which is generated within the solenoid which is storing the energy

so that gives you an idea of the kind of energies that we can store in magnetic fields in this solenoid now all this time we have calculated situations where the magnetic field was uniform

so i had taken a toroid where the magnetic field was almost assumed to be uniform then i took a solenoid but the magnetic field was uniform and i want to take an example where the magnetic field may not be uniform

so this is a non uniform magnetic field

so i want to take the following an example

so i have two coaxial conductors there is a current i passing through the inner conductor in this direction and is returning from the other conductor

so ah this radius is a and this radius is b

so let me draw the two cross sections they look like this this is a this is b so current is flowing in this direction in the inner solenoid coming back in the outer solenoid sorry in the conductor

so the inner conductor carrying current in the forward direction here and the same current is reversing in the outer conductor

so e is i here and i here

so i want to calculate what is the self inductance of this per unit length

so this is a long cable for example

so i want to calculate what is the self inductance now i can calculate self inductance either by calculating the flux enclosed by this by this system or i can calculate the energy stored in the system and equate it to half li square

so first let me calculate the energy stored

so for all this i need to calculate the magnetic field in the system now this is the surface current propagating through the outer surface of this inner conductor and the inner surface of the outer conductor here first thing you can notice is because of symmetry magnetic field will not be dependent on the position along the length of the conductors magnetic field cannot have a radial component magnetic field has to be azimuthal it has to be azimuthal just like in earlier examples when you take a long infinitely long conductor it creates a magnetic field which is azimuthal which is ah circulating around the conductor carrying current

so i know that the magnetic field will be azimuthal that means in this direction this circular direction like this now because of the current i passing in the forward direction and the same current i in the reverse direction i leave it to you to show that there is no magnetic field within the con within this area here and there is no magnetic field outside this area

so the entire magnetic field is in this volume here this is the this area in which the magnetic field will be existing

so to calculate the magnetic field what do i do i take these are the two conductors and i take a circular path of radius r

so $\int \mathbf{b} \cdot d\mathbf{l}$ is equal to $\mu_0 n i$ plus

so because the magnetic field is like this and i am integrating like this i will get $2\pi r$ into b is equal to $\mu_0 n i$

so b is equal to $\mu_0 n i$ by $2\pi r$

so thats a magnetic field and that magnetic field only exists between ah a less than r less than b and for r less than a magnetic field is zero for r greater than b magnetic field is zero

so i leave it as a problem to please show that there is no magnetic field for

distances less than a and there is no magnetic field for positions outside the this coaxial pair of conductors

so that's the magnetic field generated

so now I can calculate the energy density of the magnetic field u_b is equal to one by two μ_0 b^2 which is equal to one by two μ_0 μ_0 i^2 by two πr^2 which is equal to μ_0 i^2 by eight $\pi^2 r^2$ square μ_0 i^2 eight $\pi^2 r^2$ square that is the energy density stored in the magnetic field now please note here that the magnetic field is not uniform the energy density is not uniform the energy density is maximum close to the inner conductor where r is small where r is close to a and as r increases as you move away towards the outer conductor r increases the magnetic energy density decreases because magnetic field itself is decreasing

so here is an example where the magnetic flux magnetic energy density is not uniform across a cross section it varies with position now to calculate the total energy I must integrate

so let me calculate the energy in a length l let me put a smaller you know length small l

so I must take a volume

so what I need to do is the following that I take

so let me draw a figure here

so I have this inner conductor and an outer conductor

so I take a radius r and $r + dr$ this is this thickness is dr and of length l

so this is the ah the coaxial cable are going like this and I want to take a length l

so what is the ah what is the integration I need to do the

so there is no variation of magnetic field along the length

so I take a cross sectional area between r and $r + dr$ and this volume and I calculate the energy and I integrate from r is equal to zero to a to b that is from the inner conductor radius to the outer conductor radius

so what is the volume elementary volume

so this area of this multiplied by the length

so area of this is circumference of this multiplied by the thickness $2\pi r dr$ that is the area multiplied by the length of the cylinder gives me the volume of this this ah thin cylinder here

so $2\pi r$

so r is the radius of the inner circle dr is the thickness of this

so $2\pi r dr$ is the area of this multiplied by the length is the volume

so that elementary volume is equal to $2\pi r dr$ into l

so the total energy total magnetic energy is equal to integral u_b into $2\pi r dr$ into l and r goes from a to b because the magnetic field is finite only from a to b

so this is nothing but if I substitute μ_0 i^2 by eight π^2 square into 2π into $r dr$ by r^2 a to b into l

so I have substituted this electric magnetic field density μ_0 μ_0 i^2 square eight π^2 square r^2 is inside the integral and 2π comes out of integral l comes out of the integral

so this is equal to nothing but μ_0 i^2 by four π l integral a to b dr by r now dr by r is nothing but $\log r$ and if I integrate from a to b with limits I will get the total magnetic energy is equal to μ_0 l by four π into $\log b$ by a into l into i^2

so please note this integral is $\log b$ by a

so the magnetic energy stored in a length l of this coaxial conductor is this quantity multiplied by i^2 and I will write this as half $l i^2$ because

i know that the magnetic energy is half $l i^2$

so i get the self inductance l as $\mu_0 l / 2\pi \log(b/a)$

so that's the self inductance of a length l of this coaxial conductor of inner radius a and outer radius b and the magnetic field that is contained within this pair of conductors stores energy and that energy is half $l i^2$ and where l is the self inductance of this length l of the solid of this coaxial pair of conductors

so i can define a self inductance per unit length as $\mu_0 / 2\pi \log(b/a)$

so let me consider an example

so let me take a coaxial cable of a is equal to five millimeters b is equal to eight millimeters

so l is equal to $4\pi \times 10^{-7} / 2\pi \log(8/5)$ and if you do calculation this will give me nine point four ten to the minus eight henry per meter

so you can calculate this inductance here and you will get an inductance per unit length of nine point four ten to the minus eight henry per meter of this cable

so this gives you an idea of calculating the self inductance and what i have done here is actually calculated the self inductance by calculating the energy stored i have i took this problem of a pair of coaxial conductors i calculated the magnetic field the magnetic field is non uniform between the two conductors then i calculated the energy density of the magnetic field and i found the magnetic energy density is non uniform it varies as $1/r^2$ there is more energy stored closer to the inner conductor than the outer conductor because the magnetic field is decreasing as you move away from the inner to the outer conductor and then

so when i calculated the total magnetic energy i must do an integration i cannot multiply the magnetic the energy density by area

so i do an integration and that integration i carried out and i carried out by calculating the elementary volume and then calculating the total energy density and that came out to be of the form half $l i^2$ and i got the expression for the self inductance of this coaxial cable

so that's also one of the ways of calculating self inductance i calculate the energy stored and from there i can estimate the self inductance in fact for this problem i can also calculate the self inductance by calculating the flux

so for example if this is my these are my two conductors now magnetic field is going in the symmetry direction

so magnetic field is if the current is going like this magnetic is going like this is circulating around this conductor

so to calculate the flux what i must do is to take a surface perpendicular to this

so i take a surface like this of length l and i can calculate the flux through this and i leave this as an exercise to you you can calculate the flux

so magnetic flux Φ is equal to $\oint \mathbf{B} \cdot d\mathbf{a}$ which will come out to be $\mu_0 i / 2\pi l \log(b/a)$ and this can be written as $l i$ and i get an expression for l which is $\mu_0 / 2\pi \log(b/a)$ which is exactly the same as what we had obtained from energy density calculation

so both these calculations give me the same in this problem it was possible to do both types of calculations and i got the same result

so we will stop the discussion here where let me recall today we saw some demonstrations of eddy currents and then i discussed some examples of flux storage and self inductance and i showed you that when you have a magnetic field you have energy density and the energy density the magnetic field is half μ_0

naught one by two mu naught b square and using this we can actually calculate the the we can assume or we can consider the energy is to be stored in the form of magnetic field inside circuits

so stop here in the next class we will briefly discuss how to use this induced flux to generate currents ac and dc currents and we will continue the discussion electromagnetic induction thank you you