

good morning to all of you we continue with our discussion in electromagnetic induction you may recall that in the last lecture i had showed you some demonstrations of faraday's laws we saw we saw that if you have a magnet and if you have a coil here and if you move a magnet towards the coil there is a current produced in the coil and if you move the magnet away the direction of current reverses itself similarly if i fix the magnet and move the coil towards or away from the magnet there is again an induced current in the coil we also saw that if i have two coils ah in which in one of the coils if i pass current time varying current then when the current is varying there is an induced current in the second coil similarly when i move this coil carrying a current in front of the other coil there is a current which is induced in this coil

so all this form faraday's laws of induction in which faraday showed that whenever you have a changing magnetic field then there is an induced electromagnetic force in any conducting path

so this is a very important law in electrodynamics and its called fahrenheit law of induction

so where it is and we also saw that the direction of the current that is passing through the conductor changes as you change the direction of motion of the magnet

so there is another law which we had introduced lenses law which says that the direction of current flow direction of current flow is

so as to oppose change in in magnetic flux

so when you try to increase the magnetic flux through a closed conducting path then the conductor there is a current induced in the conductor which is in such a direction

so as to oppose this change

so if you if your flux is increasing then the induced current tries to reduce the flux and keep it as constant as possible similarly if the flux is decreasing the induced current is in such a direction

so as to oppose this reduction in flux and thats lenses law

so we had seen an example which i will recall now

so we had considered a conducting loop like this and we had a magnet here for example this is the north pole this is the south pole we can see the magnetic field direction here this is coming like this there is another field line going in the direction

so these are field lines passing through this conducting coil

so if i move the magnet towards the coil towards the conducting part then the flux through this path increases with time now if i call the area direction as this remember area is a vector

so this particular path can be described by an area this is the area the area is pointing downwards the magnetic field is also pointing downwards

so the magnetic flux defined is $\Phi = \int \mathbf{B} \cdot d\mathbf{A}$ is greater than zero and if i move the magnet towards the coil then the rate of change of magnetic flux with time is positive

so the flux is increasing with time flux is positive and increasing with time

so there is an induced e m f which is $\mathcal{E} = -\frac{d\Phi}{dt}$ which is negative

so the induced emf in the in this co in this loop is negative which means that the current induced is such as to oppose this increase in magnetic flux

so the current that will flow in this loop will be in this direction

so the current will flow in this loop in this direction

so that it produces the magnetic field which is upwards against the magnetic field of the of the magnet and tries to control the decrease in increasing magnetic flux

so the direction of the current in this conducting loop is determined by whether the magnet is moving towards the coil towards this loop or away from

this loop similarly if i consider the same loop and if i have this magnet with north pole and south pole and the magnet moves in this direction in this case again the flux lines the magnetic field lines are like this and if i define the area like this again then ϕ_b is still positive but $d\phi_b/dt$ is negative because as you move the magnet away from the the loop the flux is decreasing with time and this induces an emf which is minus $d\phi_b/dt$ which is positive so in this case the current will flow in the conducting path so as to maintain the magnetic field as before that means it will oppose a reduction in the magnetic flux so the magnetic field will induce a the changing magnetic flux will increase the current in this direction so this is the current which is induced so that the current in the coil in the loop produces the magnetic field which is in the same direction as the applied magnetic field and tries to decrease tries to oppose the change in the magnetic flux the decrease in magnetic flux in the coil in the conducting loop so this is essentially faraday's law of induction so essentially the ah whenever there is a change in magnetic flux through a conducting loop then there is a current induced in that loop so this change in flux could be because the magnetic field is changing with time or there is a motion between the coil and the magnet and anything like anything which changes the flux through this conducting loop is going to cause a change in flux which will cause an induced emf so let me consider an example a numerical example to see what kind of emfs are introduced so let me assume there is a magnetic field pointing towards me uniform magnetic field pointing towards me so these are the point tips of the arrows which are pointing towards me uniform magnetic field so in this let me consider a coil a loop of wire of some radius r so i have a uniform magnetic field p and let me assume that magnetic field is increasing with time and let me assume that the rate of increase is of magnetic field is about point zero four tesla per second so this uniform magnetic field could be produced by a solenoid within the solenoid there is uniform magnetic field or by some mechanism i generate a region in which there is a uniform magnetic field and the rate of increase of magnetic field is 0.4 tesla per second now let me assume the conducting radius of the conducting loop radius of the conducting loop r is equal to five centimeter and let the resistance of the loop r is equal to five ohms so i have a conducting loop of radius five centimeter placed in a uniform magnetic field and that magnetic field is increasing with time i am as an example i consider a radius of five centimeters of this current carrying conducting loop and the resistance of that loop is five ohms now what is the induced emf let us calculate the induced emf is equal to minus $d\phi_b/dt$ now what is the magnetic flux magnetic flux is nothing but because the magnetic field is uniform the magnetic flux flux passing through this loop is simply magnetic field multiplied by area now i am going to assume that the area is pointing towards me so that is it is in the same direction as the magnetic field so the area vector of this loop is pointing up towards me so the area vector is both is in the same direction as the magnetic field and so the magnetic flux is positive and given by b times a which is equal to b times πr^2

so the induced ϵ is equal to minus $\pi r^2 \frac{dB}{dt}$
so this is equal to minus π now radius of the loop which I have assumed is 5 centimeters

so 25×10^{-4} meter square into $\frac{dB}{dt}$ I had assumed a rate of increase of magnetic field as point zero four tesla per second

so this into point zero four and that is approximately equal to point zero three point three one four milli volt

so you can multiply and you can find that this is approximately 0.314 millivolt of emf generated in the coil in the conducting loop now this emf will drive a current now because the magnetic field is increasing with time the area is pointing up

so emf calculation must have been like this

so that the as I mentioned before the emf has to be calculated by integrating over the loop

so because the area is pointing up according to right hand rule the integration must be carried out in this direction and because I find that the emf is negative it implies that the current must be in this direction the current must be flowing in this direction

so that it opposes this current will produce a magnetic field pointing downwards and this magnetic field will oppose the change in magnetic flux because of the increasing magnetic field

so the current I can calculate induced current i is equal to emf by resistance which is equal to zero point three one four ten to the minus three volts divided by five ohms and that is approximately 63 microamperes

so there is a induced current of 63 microamperes in this loop

so as you increase the magnetic field with time at this rate of 0.04 tesla per second then this magnetic field will induce an emf in this loop

because the magnetic field is increasing with time the induced emf is negative and this negative is with respect to integration in this direction because this is because I am considering area to be pointing up the magnetic flux is positive

so this area is corresponding to a line integral in this direction

so because the emf is negative the actual current which will flow in this direction in this in this conducting loop

so this increasing magnetic field will induce a current in the conducting loop and in this example the current comes out to be about 63 microamperes of current now let me look at another example suppose I had a very very long solenoid with a coil like this and let me assume that inside the solid very long solenoid there is another small solenoid kept

so let me call this solenoid S_1 and there is also a wire in this solenoid this I call S_2 solenoid S_1 is the outside solenoid and there is a current flowing through this

so this current creates a magnetic field within the solenoid and because the current is flowing like this you can see the magnetic field is like this

so this current carrying solenoid produces magnetic field in this direction

so the inside solenoid actually has a flux passing through that solenoid if I change this current i passing through the outside solenoid I will change the magnetic field within the solenoid with time the changing magnetic field within the solenoid will change the flux passing through the inner solenoid with time the changing flux within the inner solenoid will result in an induced emf in the solenoid inner solenoid and if the circuit is complete then it will induce a current in the inner solenoid

so let me assume that the solenoid

so a very long solenoid S_1 with n_1 turns per unit length let me assume current through S_1 is equal to i_1

so this produces the magnetic field within s_1 of $\mu_0 n_1 i_1$ let me call this B_1 this is uniform within the solenoid

so there is a uniform flux passing through the inner solenoid and let me assume that the inner solenoid in a small solenoid s_2 has a total number of turns of n_2 total and the radius of s_2 is equal to r_2

so r_2 is the radius of the inner solenoid and it is carrying a total number of turns $n_2 l$ which is equal to the number of turns per unit length of the inner solenoid multiplied by the length of the solenoid i_1 would need only the total number of sol turns in this inner solenoid

so i_1 am just calling it $n_2 l$

so what is the magnetic flux per turn passing through s_2 which is equal to magnetic field into area which is equal to $\mu_0 n_1 i_1$ into πr_2^2 r_2 is the radius of the inner solenoid

so the area of the inner solenoid is πr_2^2 the magnetic field produced by the outer solenoid within this within the outer solenoid is $\mu_0 n_1 i_1$

so $\mu_0 n_1 i_1$ into πr_2^2 square

so the total flux through s_2

so each turn has this much flux and there are $n_2 l$ terms

so the total flux will be $\mu_0 n_1 n_2 l i_1$ sorry i_1 into $n_2 l$ into πr_2^2 square

so it is dependent on the total number of turns because each turn has this flux

so i_1 multiply by the number of turns in the solenoid get the total flux

so i_1 can calculate immediately the induced emf minus $d\phi/dt$ which is equal to

so the flux is

so much

so this is minus $\mu_0 n_1$ into l πr_2^2 square into $d i_1$ by $d t$ so if

so this is the flux total flux

so the flux will change if i_1 change the current through the outer solenoid

so if i_1 changes with time the flux through the inner solenoid will change with time and the rate of change of flux is this which is the induced emf which is minus of this is the induced emf

so if the outer current does not change with time there is no induced emf in inner solenoid the moment i_1 change the outer current as a function of time there is going to be an induced emf

so as an example let me assume n_1 is thousand hundred turns per centimeter a current i_1 of one ampere let me assume $n_2 l$ is equal to hundred total number of turns and radius of the inner solenoid to be one centimeter and let me assume that the current i_1 changes from one ampere to zero in 10^{-3} milliseconds

so this will give me a rate of change of $d i_1$ by $d t$ is minus 1 by 10^{-3} to the minus two seconds which is equal to minus hundred ampere per second

so i_1 change the current i_1 switch off the solenoid and change the current for example from one ampere to zero amperes in a time of hundred ah ten millisecond and

so let me assume its a constant decrease in current as a function of time

so $d i_1$ by $d t$ remaining constant and thats minus hundred amperes per second

so the induced emf is equal to

so i_1 must substitute this

so this is minus four by ten to the minus seven which is the $\mu_0 n_1$ is ah n_1 i_1 have given has hundred tons per centimeter that is ten to the power four turns per meter into $n_2 l$ which is hundred into πr_2^2 which is π

into πr^2 which is π have assumed a radius of 1 cm
so that is 10^{-4} m^2 into $\mu_0 n i$ which is
 $100 \text{ amperes per second}$ and we can substitute all this and get approximately 39.5 millivolts

so the inner solenoid has an induced emf of about 39.5 millivolts

so that is actually this is a negative sign there is another negative sign
so this becomes positive

so induced emf is positive and that is equal to 39.5 millivolts

so whenever i change the current in the outer solenoid i am going to induce a
 emf in the inner solenoid and that induced emf in this example with these
numbers comes out to be about 40 millivolts of emf and depending on the
resistance of the inner solenoid and if the circuit is complete you will have a
current flowing through that and that current will be determined by the induced
 emf and the resistance of the inner solenoid now let me look at another
interesting example in the same solenoid situation

so let me assume that i have a long solenoid again

so this is my solenoid very long solenoid with current loops like this very
long solenoid and let me assume a conducting loop placed outside the solenoid
coaxial with this solenoid

so there is a conducting loop here and this is a galvanometer just to see the
current flow flowing through that

so i connect a galvanometer and a coil outside and a in the loop of by an outside
this is a very long solenoid now

so this is another example now the question arises as to what will happen if i
change the current in the solenoid the first thing to notice is that the
solenoid has if the solenoid is in principle infinitely long very long the
magnetic field outside the solenoid is extremely small it is very almost
negligible its zero if the solenoid is infinitely long but otherwise it
will be a small a very very small value now if i change the current in the
solenoid the magnetic field inside the solenoid is changing with time but if i
look at this outside conducting loop the flux through that loop is changing with
time

so according to faraday's law there must be current induced in this conducting
loop please note that if i change the current in the solenoid the current in the
solenoid changing gives me a changing magnetic field inside the solenoid the
changing magnetic field inside the solenoid implies that the magnetic flux
passing through this conducting loop changes with time and according to
faraday's law there must be an induced emf in the conducting loop and

so it will generate a current

so the galvanometer should show me a deflection now in this case there is no
moving conductor

so there is no lawrence force in fact the magnetic field itself is almost
negligible outside

so what is happening why is there current in the outside conductor its simply
because a changing magnetic field produces an electric field

so this changing magnetic field within the solenoid is actually generating a
electric field an electric field outside and that electric field is what is
driving the current through this outer conductor please remember earlier i
mentioned its an electric field it is not an electrostatic field because the
electrostatic field the work done in completing one complete cycle from a
complete loop is zero but this one is an induced emf electromagnetic force and
so this is generating an electric field which is actually driving the charges

so this is an example where the changing magnetic field is generating an electric field

so let me calculate the the induced current here

so let me assume the area of the solenoid is equal to πr^2

so r is the radius of the solenoid and

so if the solenoid for a very long solenoid the magnetic field is equal to $\mu_0 n i$ where n is the number of turns per unit length and the current is i the current flowing through this solenoid is i

so $\mu_0 n i$ is the magnetic field

so flux through the conducting loop is equal to $b \pi r^2$ remember there is magnetic field only within the solenoid the loop is much bigger than the solenoid but there is hardly any magnetic field outside

so the flux is simply $b \pi r^2$ which is nothing but $\mu_0 n i \pi r^2$

so if i now change the current as a function of time that current changing with a function of time changes the flux through this outer conductor and that should induce an electric field and an induced emf

so what is the induced emf now $-\frac{d\Phi}{dt}$ which is equal to $-\mu_0 n a \frac{di}{dt}$

so this emf is actually generated in the outer conductor and

so what is actually happening is as i change my current in the solenoid the magnetic field is changing with time and a changing magnetic field is generating an electric field outside and that is that electric field which is driving the current through the outside conductor and

so if i define \mathcal{E} as $\int \mathbf{e} \cdot d\mathbf{l}$

so if i the emf is defined as the work done in taking unit charge across one full revolution here and that is $\int \mathbf{e} \cdot d\mathbf{l}$

so this is an electric field and not an electrostatic field and this is equal to $-\frac{d\Phi}{dt}$ which is equal to $-\mu_0 n a \frac{di}{dt}$

so this changing current in the inner in the solenoid is actually generating a changing magnetic field and that changing magnetic field is inducing an electric field outside in the in the conducting loop now let me try to estimate what is the electric field produced by this changing current

so for this let me draw this same figure a cross section of this figure cross section of this figure let me draw

so let me this is my solenoid and let me assume that the magnetic field is pointing inwards uniform magnetic field pointing inwards and my conducting loop is outside

so let me draw the conducting loop concentric with this that is the conducting loop outside

so for $\frac{di}{dt} > 0$ if you look at this for $\frac{di}{dt} > 0$ induced emf is negative emf is negative now please remember the magnetic field is pointing downward

so if i want to if i have defined the flux as positive the integration loop must be in this direction because the magnetic field is pointing downward in $\mathcal{E} = \int \mathbf{e} \cdot d\mathbf{l} = -\frac{d\Phi}{dt} = -\frac{d}{dt} \int \mathbf{v} \cdot d\mathbf{a}$ this is the magnetic flux rate of change of flux minus rate of change of magnetic flux is emf which is $\int \mathbf{e} \cdot d\mathbf{l}$

so this is over a path c and this is over an area a

so there has to be consistency between the definition of the path c in which direction should i integrate and the area

so if i call the area downwards as positive the integration must be in this direction and because the integration is this direction and if the current increases with time induced emf is negative that means the electric field must

be pointing in the up in this direction as i will show you

so electric field at this point ah this electric field must be pointing in the direction in the other direction

so that integral $\mathbf{e} \cdot d\mathbf{l}$ becomes negative if i integrate like this if i integrate like this because that is the direction of integration i must get a negative value

so the electric field must be pointing in the opposite direction now remember in my earlier lectures i have used symmetries to estimate the directions of the fields electric field in terms electrostatic field in when we were discussing gauss's law magnetic field direction in the case of ampere's law and i want again use some symmetry here the first thing is because the solenoid is assumed to be infinitely long the electric field has to be cannot have a z component cannot have a component like this it must be in this plane it it has to be independent of this angle because it has to be the same in all orientations here because the system is completely symmetric

so the electric field here here here at a given distance from the center must be exactly the same also it cannot have a radial component because if it had a radial component then it will imply according to gauss's law that there are some charges inside and i know there are no charges inside no positive charges if there are positive charges it will give me an electric field outward direction and because there are no charges here electric field cannot have a radial component

so it must have only an azimuthal component that means electric field must be pointing like this this point like this here is like this here like this here like this here like this

so this is electric field direction okay i am using some symmetry arguments to say that the induced electric field because of the changing magnetic field must be in this direction because of symmetry it cannot have a z dependence electric field has to be in this plane it cannot have a radial component according to gauss's law

so it has to be a component which is like this and

so and it has it is the same at all points

so this i can immediately integrate

so integral $\mathbf{e} \cdot d\mathbf{l}$ ah is equal to two pi into if this distance is r r into e two point r into e and that must be equal to minus mu naught and a d i by t t which is the rate of change of flux

so the electric field induced is actually minus mu naught and a by two pi r d i by dt very interesting because this electric field which is induced by the changing magnetic field within the solenoid will now push a charge in this direction and that will induce a current if there was a conductor here it will induce a current and that current will flow like this and that current will try to oppose the change in the increase in current

so if the current is the d r by d i is positive then the electric field will be like this if i d i by d i is negative the electric field reverses itself in direction

so please let me redefine again in the induced emf it is called an electric field in this case integral $\mathbf{e} \cdot d\mathbf{l}$ is not equal to zero for electrostatic fields integral $\mathbf{e} \cdot d\mathbf{l}$ is equal to zero

so this is a different this is an electric field that's why i am calling an electric field and that field is exactly the similar electrostatic field it has the same char force on a charge q e but that electric field is what is called as non conservative that means it that integral of $\mathbf{e} \cdot d\mathbf{l}$ is not equal to zero

so let me calculate some value here

so ah for this example

so r small r is the radius of the axis of the solenoid
so let me assume as an example axis number of turns per unit length n is equal to 1000 per meter axis let me assume $d i$ by $d t$ is equal to hundred amperes per second area of the solenoid is equal to axis pi into twenty five ten to the minus four meter square i am assuming a solenoid of radius five centimeters

so and i want to calculate

so this this radius is this radius is 5 centimeters and i want to calculate a distance of 10 centimeters from the center of the solenoid

so i want to calculate what is the electric field induced electric field at r is equal to ten centimeter

so i want to use this equation which we have derived this is the equation

so let me rewrite it again here

so e is equal to minus μ naught n times a by two pi r $d i$ by $d t$

so let me substitute the numbers minus four pi ten to the minus seven into thousand turns per meter into area of pi into twenty five ten to the minus four meter square $d i$ by $d t$ is hundred amps per second divided by two pi into capital r is ten centimeter that is point one meters and we can calculate this this comes out to be about one point five seven into ten to the minus three volts per meter

so with minus sign here and this sign essentially

so the direction of the electric field one has to remember and this is the magnitude of the electric field is about one point six millivolts per meter

so this changing magnetic field within the solenoid is actually causing an electric field to be generated outside in fact its generated everywhere whatever the rate the distance is you will have an electric field generated

so this is a very interesting situation where a changing magnetic field generates an electric field and this electric field is different from an electrostatic field

so it can do work and this electrostatic field electric field is actually leading to an emf and that emf is responsible for driving a current in a conducting path

so these were some examples of ah faraday's law of induction which showed me that ah a changing magnetic flux through a through a conducting path will induce a current through that an emf induced emf which if the path is conducting then it will lead to a current in the conducting path now please note that even if i do not have a conducting path i will still generate an electric field an emf in any chosen path that you want to integrate and that induced emf will depend on the flux rate of change of flux through that path

so as we have seen in the earlier example in this case of the solenoid and a path outside in this case of a solenoid which is like this and the magnetic field is like this at this point there is an electric field irrespective of whether there was a conducting coil or not which means that this electric field will be generated in space a changing magnetic field will generate an electric field in space and that electric field can lead to a current if there was a conducting path

so if there was a conductor here this will lead to current going like this and if there is no conducting path there is still an electric field that is generated in space

so this is a very very important law in electro dynamics that a changing magnetic field can generate an electric field now these are examples in which the emf is generated simply by changing the flux of the magnetic field ah another kind of emf which is understood in terms of lorentz force is called motional emf let me take an example of a motional emf

so let me take a magnetic field pointing downwards uniform magnetic field

pointing downwards

so these are the ends of the arrows

so magnetic fields are pointing down and uniform now let me take a conductor a conductor like this and move this in this direction

so this is the conductor this conductor state conductor i am moving the magnetic field like this now what is going to happen there are electrons in the conductor and because the electro when i move the conductor the electrons start to move motion of the charge in a magnetic field will induce a lorentz force on the charge

so an electron moving like this with the magnetic field pointing downwards $v \times b$ is upwards $v \times b$ is upwards but because the electron has a negative charge the force is downward

so $q v \times b$ is the lorentz force $v \times b$ is positive q is negative

so $q v \times b$ is downward and

so what will happen is the electrons will be pushed towards the downside to toward this end leaving a net positive charge on the other side

so there will be a negative charge here and there will be positive charge here net positive charge and this motion if i continue to move at a constant speed then the charges will accumulate in such a fashion that once the charges have accumulated these charges will generate their electrostatic field and that electrostatic field will be such that it will compensate for the magnetic force

so the force due to the electric electrostatic field will be equal to the force due to the magnetic field and then no more charge motion will take place

so if

so what is the force on the ah what is the lorentz force $q v \times b$ and because v and b are perpendicular this is nothing but $q v b$ and the electric field which will be generated will be such that $q E$ will be equal to $q v b$ that means it will generate an electric field given by E is equal to $v b$ and this will generate a potential difference between the ends of if this length is l $v b l$

so there will be a potential difference between these two ends which will ah such that if i keep moving with this constant velocity then this potential difference will generate an electrostatic force electric force on the charge in the upward direction and in the upward direction magnetic force in the downward direction and these two forces compensate

so this is simply a result of lorentz force now let me modify the problem a little bit further

so i again draw a uniform magnetic field pointing downward represented by this crosses and now what i do is the following i place another conductor like this i have a conductor like this and place this conductor which is which is i am which i am moving on this conductor

so this is the this is the length l which i was mentioning before and this is moving like this now as i move this conductor to the right electrons are exerted upon by a magnetic force

so electron motion is like this field is pointing downward

so $v \times b$ is upward $q v \times b$ is downward and the electrons will come here when the electrons come here there is a net negative positive charge left here

so electrons can now flow through this path and come back here and as they arrive here they are again pushed down by the magnetic force and they constitute an electron flow like this which implies that there is a current flowing in this loop in this direction

so this can be seen by a simple argument of lorentz force that as i move the conductor in the magnetic field the electrons in the conductor suffer a magnetic force and that magnetic force leads to a movement of this electron through the

conductor and that conductor leads to it then this moving electrons context constitute a current now i can picture this from a different perspective according to faraday's law when i move this conductor in front of this i am changing the area of this conducting path and as i change my area of the conducting path i am changing the magnetic flux through this conducting path and i know that an changing magnetic flux leads to an induced emf

so please note this in this argument in faraday's law using faraday's law as i move this conductor to the right i am changing the area

so if i am here i have this area if i am here i have a little more area if i am here more area

so as i move my conductor to the right i am increasing the area of this conducting path and as i increase my area of the conducting path i increase the magnetic flux through the conducting path and a change of magnetic flux leads to an induced emf

so in this path i must see an induced emf and once there is an induced emf that will lead to a current now let us see what happens

so if i move to the right i am increasing the area with time

so if i were to look at area vector downward i am increasing a magnetic flux with time

so induced emf must be negative

so if i move like this because the area is pointing downward the the emf calculation must be in this direction

so i must look at the emf direction like this but e m f happens to be negative

so e m f induced e m f must be like this which will induce a current in this direction exactly like what we have got from lawrence force from lorentz force as i move this conductor electrons in the conductor are pushed down and they then constitute a current through the conducting loop

so as i move here the conducting loop there is a current flowing through the conducting loop because of laurence force the other interpretation is equivalent interpretation is that as i move my conductor to the right i am changing the increasing the magnetic flux through this area if i define my area as downward magnetic flux is positive

so the magnetic flux increases in magnititude with time and its also directed downward

so to be consistent my emf calculation must be in this direction

so because $d\phi$ by dt is increasing with time emf induced is negative

so if i integrate like this i get a negative value of e m f that means the current must be flowing in this direction exactly like from lorentz force

so what is the

so let me assume that the resistance is r

so let me assume that this part of the conductor conducting path has almost no resistance and it is primarily this path

so as i change my area the resistance is assumed to be remaining constant

so i am assuming that only this part of the conductor has a resistance the remaining part of the conducting circuit has almost negligible resistance

so the resistance is r

so the current induced is equal to emf by r and e m f we have just calculated e m f is v times b times l

so this is equal to $v b l$ by r now there is a current flowing through this conductor in this direction

so now what happens when i move in the conductor i am now moving a current carrying conductor in a magnetic field my movement of the conductor induces a current in the conductor induce the current in the entire circuit this part of the conductor is now moving and i know that a current canning conductor has a

magnetic force acting on it

so what is the magnetic force on the current carrying conductor of length l in a magnetic field b perpendicular to it. l cross b l is the length and because l and b are perpendicular to each other this is nothing but $i l b$ and i is the current. I have calculated

so this is equal to $b^2 l^2 / r$ that is the magnetic force on the current carrying conductor

so what is the directional magnetic force

so the current is now flowing like this

so l cross b the force is magnetic force is towards the left it is

so I am trying to move the conductor to the right the magnetic force is pulling it to the left and this is exactly what is happening because of the induced direction of the current

so the current induced current is

so as to oppose the change which I am trying to do

so when I if I have to pull the conductor I must do work against this magnetic force on the current carrying conductor the other parts of the conductor are not moving

so this is the one which I am trying to pull when I am trying to pull this conductor there is a current in the conductor there is a magnetic force on the conductor and that magnetic force happens to be to the left I am trying to push it pull it to the right

so I must do work against this magnetic force

so let me calculate what is the work done per unit time this is equal to force into velocity which is equal to

so the force is $b^2 l^2 / r$

so $b^2 l^2 / r$ into velocity which is equal to $v^2 b^2 l^2 / r$

so this is me this is the work that I am doing per unit time in pulling this conductor

so here is my conductor and if everything is at rest there is no induced current the moment I start to move it as if I start to move it because of Lorentz force or because of Faraday law of induction you can use either of them you find that there is an induced current in the circuit the induced current direction is like this you which you can interpret either from Lorentz force law or from rate of change of magnetic flux

so you have an induced current like this

so on this wire which I am on this conducting rod which I am trying to move there is a current flowing in this direction

so the current carrying conductor has a magnetic force we have we have seen earlier that you have a if you have a current carrying conductor in a magnetic field there is a force on the conductor and for a length l the force is simply given by i into l cross b current into l cross b and that force because of the direction of the current the magnetic force is towards the left

so what is happening now is I am trying to pull it my pulling induces a current that current then is acted upon my magnetic force pulling it towards the left

so I have to do work against this magnetic force and

so the work which I am doing per unit time is simply given by $b^2 l^2 v^2 / r$ now because there is a resistance in the circuit if you have a current i passing through a resistance we have seen that there is a joule heating that means if you have a current i in a resistance r the power consumed is $i^2 r$ the current into resistance

so we have calculated the value of the current $v b l / r$

so I get $v b l / r$ whole square into r which is nothing but $b^2 l^2 v^2 / r$ exactly the same as the work that I have to do to pull the wire

so what is actually happening is the force that i am applying to pull the wire to the right is being used up for heating the conducting path to the joule heating

so i need to do work and this is a very interesting example of how the work that i am doing on moving the conductor is being used up in joule heating

so this was the next example in which i could employ either lawrence law lawrence force law to calculate the show that is an induced current or the magnetic parity law of induction but please remember there are other situations where nothing is moving and a change in magnetic flux or magnetic changing magnetic field through another mechanism can lead to an induced emf and that is the most general form of faraday's law

so we will continue with this discussion on faraday's laws of induction in the next class thank you you