

a very good morning to all of you today we will start a a very important topic that is electromagnetic induction till now we have been studying magnetic fields produced by current kinetic conductors forces between current carrying conductors and

so on

so remember i had shown you a demonstration which hence christian oyster had done in nine eighteen twenty to show that currents produce magnetic fields current carry conductors produce magnetic fields and then we studied ah magnetic fields produced by a straight current carrying conductor magnetic fields produced by solenoid and

so on now today what i am going to discuss is a very very important topic in electromagnetics and that is electromagnetic induction

so when ah it was shown that electrical currents create magnetic fields the obvious question that arose is can magnetic field produce currents can magnetic fields produce current that means can i use a magnetic field to generate current

so lot of experiments were carried out by many scientists by placing very strong magnetic fields magnets around conductors by passing current through conductors close to another conductor and they didn't find much successful results in generating currents until michael faraday in 1831 did a series of extraordinary experiments to show that to generate current i need a changing magnetic field something should change and that change will result in an electrical current now michael faraday was a very famous scientist british scientist and he has contributed significantly to electromagnetics electrochemistry and

so on he lived in the period michael faraday seventeen ninety one to eighteen sixty seven

so he did some outstanding experiments in electromagnetics and also electrochemistry he also introduced study diamagnetic properties he was an excellent experimentalist and in fact albert einstein had a picture of michael faraday in a study room along with pictures of sir isaac newton and also james clark maxwell we will study about maxwell's equations later on but michael faraday was a very very important scientists in the in the development of electromagnetics and today what i am going to show you is some experiments similar to what michael faraday did at that time to show relationship between magnetic fields and currents we have till now studied that currents produce magnetic fields i will now show you that it is also possible to generate currents using magnetic fields but under certain situations

so let me first show you a solenoid which i have wound by taking a piece of copper wire and here is a solenoid and these are the two ends and you can see here there are windings around the solenoid and this solenoid as you know can create a magnetic field

so this is one solenoid there is another solenoid here which is a smaller solenoid and that has a larger number of windings and i want to show you that this solenoid will produce magnetic field

so what i do is here is a compass here is a compass which produces which is which contains the north and south poles and i connect this solenoid to a battery and you can see immediately the the magnetic coil is rotating then this particular solenoid generates magnetic field

so this is essentially an experiment to show that currents generate magnetic fields now i want to show i want to see whether magnetic fields can generate currents now before that i want to show ah there are two permanent magnets here which i had shown in an earlier experiment these are two permanent magnets very strong permanent magnets and as you can see here it has a very strong effect on ah the the needle

so this is a soft iron piece a larger number of pieces of soft iron and ah this is formed into a cylinder here large number of pieces and this particular piece i connect to a magnet the moment i put a magnet here the magnetic field of the magnet actually gets concentrated into this and this soft iron piece gets magnetized and has a magnetic field associated with it

so this particular this is now becoming a slightly long magnet

so what i want to see is whether this magnet this magnetic field produced by this structure can generate electric currents now for this what i have done is here i show you ah a galvanometer you can see here in the third part there is a galvanometer there is another solenoid and this solenoid is connected to the galvanometer

so this is one terminal of the solenoid another terminal of the solenoid there is no source of current in the solenoid and

so the galvanometer is showing zero reading the galvanometer can shift to the right or to the left depending on the direction of the current for one direction of current the needle will shift to the right for a reverse direction of the current the needle shifts to the left

so depending on the direction of the current the needle of the galvanometer will shift to the right or to the left and

so we will now investigate this

so this magnetic magnet now what i want to do is i want to ah put this inside this solenoid

so that this magnetic field associated with the solenoid

so there is a magnetic field which is connected to the solenoid

so now you see there is a strong magnet within the solenoid there is a strong magnetic field but it does not generate any current

so a static magnetic field connect which is ah around a circuit a coil does not create any magnetic field any current in this in this coil now what i want to show you is if i change the magnetic field by pulling out or pushing in this soft iron piece i will generate a current in the galvanometer which will be seen in the galvanometer

so what i am going to do is the following i am going to pull the soft iron piece out of the solenoid or push it in

so what am i doing because there is a magnetic field associated with the soft iron piece which is connected to a magnet there is a magnetic field associated with this soft iron pieces and when i pull the soft iron piece i am changing the magnetic field encircled by the solenoid

so i am changing the magnetic field whether i pull it or push it i am increasing or decreasing a magnetic field which is which is which is encircled by the solenoid

so this was one of some of the experiments carried out by michael faraday

so let me show you

so here is the ah current in the in the in the galvanometer you can see now let me pull the solenoid the soft end piece out of the solenoid you see the needle shifted to the right and there was a short current generated when i was pulling it out

so when i pull the the soft iron piece out of the solenoid i am changing the magnetic flux in the solenoid and that change in magnetic flux generates the current now please note that when i pulled the soft iron piece out of the solenoid the current was generated where the needle shifted to the right of the zero now i want to do the same experiment but push the soft iron piece into the solenoid and to see what just happens ok now let me push the solid let me push the soft line into the solenoid as you can see here when i push the soft iron piece into the solenoid the current generated is to the left

so when i pulled out

so for example let me pull it out again if i pull it out the needle shifts to the right and if i do not move the soft iron piece there is no current

so the current got generated only when i was moving the soft iron piece or when i was changing the magnetic field

so now if i push it here the current is again generated as i am moving and the current is now opposite to the direction of the current that was produced before now let me pull it and push it very slowly if i pull it out very slowly the amount of current generated is very little as you can see here there is a the needle shifts to the right very little very little current if i stop the current becomes zero if i move it into the solenoid at a slow pace there is a very small amount of current generated but it is to the left

so it is opposite thyroid and current

so it looks like the current generated also depends on the speed at which i am moving the mac moving the soft npc

so if i move it fast it moves quite to the right if i move it quickly here then it moves to the left

so two things i am observing that there is no current generated if the magnetic field remains constant the magnetic field produced by the soft iron piece which is going through the solenoid is remaining constant if i do not move the magnet and in that case there is no current generated if i pull the soft iron piece i am changing the magnetic field as a function of time and as long as i am moving there is a current generator and i have also shown you that the current generated depends on the rate at which i am pulling it which means the current generated depends on the rate of change of magnetic field now we will quantify this two equations a little later but it is important to notice that the current generated in the circuit depends on the rate of change of magnetic field and the second observation which i have seen is if when i am pulling the current is in one direction when i am pushing the iron piece the current is in the reverse direction

so it also depends on the direction of the current in the circuit depends on whether the magnetic field is increasing with time or decreasing with time

so again we will quantify this and understand this

so let me repeat once more here is my solenoid here is the galvanometer i i pull it and it moves to the right and if i stop pulling it there is no movement if i push it it moves to the left again as long as i am pushing it is moving if there is a current but then it comes to zero

so if i move it very slowly there is some current generated but very little current generated as compared to fast motion to the right here and if i move to the left then it is a small current generated if i move very slowly is hardly any current generator

so the rate of change of magnetic field decides the amount of current generated so that is one experiment now let me do another experiment with the same

so what i have done here is i have moved the magnetic i moved the magnetic soft iron piece with the solenoid now let me fix the iron piece and move the solenoid so if i move the solenoid to the left i am not i am not moving this iron piece but i am moving the solenoid if i move the solenoid to the left there is current generated if i move it to the right again currently generated

so you see if i move it like this there is a current to the right if i move it like this this is the current to the left very interesting that the same kind of current is generated irrespective of whether i move the magnet with respect to the solenoid or the solenoid with respect to magnet this is a very very important concept that whether the magnet is moving with respect to the coil or the coil is moving with the expected magnet i am generating a current in the

coil

so again let me show you here

so i move the solenoid to the left and there is a current generated if i move the solenoid to the to the other side then the opposite current generated very similar to exactly similar to what happens when i move the magnet rather than the coil

so that's another very very important observation the amount of current generated depends only on the relative motion between the magnet and the coil that's a very very important consideration now now let me do another experiment which michael faraday did at that time

so i remove the permanent magnet and i take another solenoid here is another solenoid which i am taking i take the solenoid which has two wires here and i place the solenoid around this soft hand piece

so let me remind you that if i connect this to a current source if i current the solenoid connect the solenoid to a current source that current source will pass current through this small solenoid that small solenoid will then generate a magnetic field that magnetic field will then pass through the second solenoid and then i will show you i will check whether there is a magnetic field generate current generated in the second coil or not

so for this i take a battery this is a battery here nine volt battery

so i connect this to the solenoid to one of the first solenoid here

so you see if i when i connect there is a movement when i disconnect there is a movement but when there is no there is constant current for example here i am constantly passing a current there is no current in the sec in the second transform in the second solenoid if i disconnect there is a current in the ah the solenoid connected to the back the galvanometer if i connect again there is a current generated in the solenoid if i disconnect there is a current

so i do not need a magnet to generate a current a current in the solenoid in the solenoid a current which is passing through the solenoid generates a magnetic field that magnetic field is passing is encircling enthralled by the solenoid which is connected to galvanometer

so when i connect this first solenoid into the battery source i pass a current through the solenoid and that current generates a magnetic field and only you can see here the current is there only when i connect at the point of connection or when i disconnect if there is a constant current flowing through the coil there is no current generated in the galvanometer as you can see here moment i disconnect there is a reflection moment i connect there is a deflection

so in this case in the first case the magnetic field was produced by a permanent magnet a permanent magnet and through this soft line piece

so irrespective of whether i move the magnet with respect to the coil or the coil with respect to magnet i am seeing an induced current generated in the in the coil secondly the direction of the induced current depends on whether the magnetic field is increasing with time or decreasing with time then i did an experiment in which i have a solenoid in which i pass the current this solenoid those are the cut the this solenoid when i pass the current generates the magnetic field that magnetic field passes through this solenoid and when i connect a battery to this solenoid i am changing the magnetic field generated by this solenoid and the change in magnetic field seems to induce a current in the solenoid if i disconnect again the magnetic field goes from maximum to zero in that process i again generate a current in the solenoid the direction of the current in the two cases are opposite to each other that's a very very important consideration we must know

so as you can see here there is a magnetic field generated irrespective of whether i move the magnet with respect to coil or i move the coil with respect

to magnet or i have another coil which is producing a magnetic field and i change the current in that second other coil

so all these are producing a current in the in the solenoid and that current is called an induced current and that induced current seems to be appearing whenever the magnetic field changes

so when i move the magnet inside the solenoid i am changing the magnetic field through the solenoid and it induces the current when i move the solenoid and fix the magnet i am changing the magnetic field through the solenoid which also induces the current i put another coil near this coil and change the current in the back in this coil and i change i change the current passing through the coil which changes the magnetic field passing through this coil in which i am measuring the current and that induces the current

so these were some observations which michael faraday did in eighteen thirty one and which ah which opened up the entire field of electromagnetic induction and which is today a very very important part of modern machinery including transformers generators and

so on which are all working on the principle of electromagnetic induction

so a current produces a magnetic field a constant magnetic field does not generate a current a changing magnetic field seems to be generating a current and this is called faraday's law of induction and we will discuss the mathematical principles behind the parallel faraday's laws of induction

so what are what have i shown ah moving a magnet near a coil generates the current in the coil moving the coil in front of a magnet it generates a current in the coil the direction of current depends on the movement the movement towards or away ah placing another coil nearby and changing current through that coil generates a current

so all these observations were essentially coming out of the experimental experiment we have performed

so we will quantify all this into what is called as faraday law of induction a very very important part of electromagnetics ok now i want to show you another interesting experiment of magnetic levitation in which i will show you that using magnetic forces we can suspend an object and some of these principles are today used in magnetic magnetic levitation trains maglev trains

so i want to show you another experiment in which i will use another property of magnetic fields and mag induced currents to levitate a another object yeah now let me connect to the other circuit

so i want to show you some very interesting experiment ah which is an experiment which shows how magnetic effects can lead to levitation

so this is a variac which actually ah decreases the 220 volts which is coming on the main line to any volte which i want by rotating this knob here this is connected to the same solenoid as before and there is a soft iron inside and that soft iron piece is actually ah concentrating the magnetic field and as we have seen before the magnetic field can become very strong inside the solenoid because of the presence of the soft hand piece because the soft iron gets magnetized and that magnetized material produces its own magnetic field adding to the magnetic field produces produced by the current and which results in a very very strong magnetic field

so i want a strong magnetic field inside the solenoid and i have put a piece of aluminium here thats an aluminium piece ah no please remember that aluminium is non magnetic it does not get attracted to magnets as you can see here its not getting attracted to a magnet at all this is non magnetic and

so this is an aluminium piece and i am going to place this inside the inside this soft end piece now what i am going to do is the following

so let me explain i am going to

so its just connected to the very to the variac right now the variac has zero voltage

so there is no current passing through the solenoid and i have connected this through a resistance here just to make sure that i have control on the current that is passing through the solenoid

so now what i am going to do is i am going to slowly increase the current in the solid in the solenoid and as i increase the current the magnetic field increases and please remember the current which is passing through the variac and through this is a alternating current the current is changing with time its changing at the rate of 50 times per second and it is a 50 hertz current

so the current is continuously changing with time which implies that the magnetic field generated by the solenoid is changing with time at 50 hertz and

so the flux passing through this the magnetic magnetic fields seen by this is changing with time at the rate at which the current is changing with time

so as we have seen in the earlier demonstrations a changing magnetic field induces a current in a in a material and

so what will happen is when i change my current here i will induce a current in this aluminium piece and we will see what happens now

so let me start to increase the current in the ah solid in the solid in the solenoid and i put a screen here

so that becomes very visible

so now let me start to increase my current here and you can see here the aluminum ring is floating in air its floating because of the magnetic repulsion between the solenoid and the aluminium piece now let me reduce the current as i reduce my current the piece comes back to the original position if i increase my current here again the aluminium coi the aluminium piece lifts itself and i can raise it to quite a height here by changing the magnet by by inducing currents here

so what is actually happening is the current through the solenoid is changing with time that changing current in the solenoid changes the magnetic field passing through this soft iron piece the changing magnetic field which is changing through this aluminium now ring is inducing a current in the ring these are called eddy currents those currents are in a direction

so as to oppose the change as we will discuss and

so there is a repulsion between the solenoid and the current that is passing through the aluminum leading to a repulsion and a levitation

so its called magnetic levitation as you can see here you can have an iron piece floating up above the solenoid simply by having an oscillating magnetic field here

so that is a very interesting demonstration of how changing magnetic fields can be used to lift up objects leading to what we call as levitation magnetic levitation that means you can lift objects above the surface simply by using magnetic fields

so now we will move on to some discussion and try to understand what is actually happening in the case of the the what is actually happening in in terms of physics will write write down some equations and try to discuss the mathematical structure behind what we have been seeing

so let me recall now again

so this was in 1831 michael faraday demonstrated this experiment to show magnetic induction

so what we have seen is the following if i have two coils one coil for example here and another coil here

so this coil is closed and if i change the current changing current in this coil in coil that we call call call it coil a induces a current in coil b

so there is a if i change the current through this coil coil a it produces a magnetic field which is changing on the circuit and this in this coil there is the current generator let's go i call call it coil b now if i also move this relative to each other either coil a towards coil b or coil b towards coil a i will have again induced currents in coil b because of the magnetic field generated by the coil a i also showed that if i have a coil and if i bring a magnet either i move the magnet like this or like this there is induced current so current gets induced in this this coil here whether i move the magnet towards the coil or away from the coil and i showed you that the amount of current generated here depends on the rate at which i am moving if i move faster i generate more current if i move slower i generate less current what i did not show here is another interesting part

so if i for example take a region containing a uniform magnetic field pointing downwards into the page as i am plotting here and if i take conductor like this for example and if i place another conductor here

so there is a uniform magnetic field in this space and if i move this conductor so this conductor this this is now a circuit and if i move this conductor i am changing the area of the circuit when i do that i find current is induced intake circuit

so if i move this faster the current is more if i move it slowly the current is less

so there are multiple situations in which current gets induced in a coil and all these observations have led us to what we call as faraday's law of induction now one thing that is significant and we need to understand is the following that suppose i have a which i showed you if i have a magnet and if i have a coil whether i move the magnet towards the coil or the coil towards the magnet i showed you there is induced current

so i fix the coil here move the magnet i will use current if i move the magnet forward and backward i fix the magnet if i move the coil back forward i have in this current same induced current whether if i whether i move this or move this i generate the same induced current in the coil and

so it only depends on the relative motion between the coil and the magnet but look here what is the physical explanation for this induced current in one case in which i have the magnet fixed but the coil moving towards the magnet

so for example if i if i fix the magnet and move the coil towards the magnet the coi the mag the circuit here contains for example let me take a circuit like this

so this is this is a circuit for example

so if i have a circuit here on a magnet if i move i showed you that if i move the magnet towards the circuit i generate magnetic field sorry i generate a current in the circuit if i move the circuit towards the magnetic magnet i also generate the same current in the circuit now let me try to understand why there should be current generated when i move this circuit towards the magnet now see here this circuit this material contains electrons free electrons conductor

so when i move this coil towards the magnet the electrons in the in the wire gets velocity in this direction there is a magnetic field generated by the magnet and we know that there is a lawrence force acting on the electrons the magnetic field produced by the magnet is acted upon as acting on the electrons in the conductor which are moving when i move the coil and that force i will show you leads to a current in this coil simple lawrence force

so there is a lorentz force acting on the electrons in the in this in this coil and that lorentz force results in a current in the coil

so i can have an explanation for the induced currents when i move the circuit towards the magnet or away from the magnet

so what happens if i move the magnet now when i move the magnet the electrons in the conductor are not moving and i still induce the same current in the coil this is a completely different explanation there is no explanation with lorentz force here because the electrons are i am not moving the conductor i am moving the magnet

so as i move the magnet i am changing the magnetic field acting on the electrons and if i assume there is no current there is no electron motion then obviously there is no variance force but still there is an induced current and this is the beauty of faraday's laws of induction it only depends on the relative motion between the magnet and the coil and in the second case when i move the magnet towards the coil actually the changing magnetic field induces an electric field and that electric field generates a current in the circuit please remember if charges will move when there is a magnetic field because of lorentz force $v \times b$ force or because of an electric field

so if i move the magnet there is no lorentz force but there is a force due to electric field generated by the changing magnetic field that is a faraday law of induction

so the very very important law which we will discuss

so let me write down the fair deal of induction

so let me ah consider a path like this

so for this i must define magnetic flux first remember we had in electrostatics we were discussing gauss's law and at that time we had defined an electro

electric flux electrostatic flux and that was used to define the gauss's law

so similarly we can define a magnetic flux
so if b is the magnetic field then we define the magnetic flux is equal to $\int b \cdot d a$ over surface s is a surface remember $e \cdot d a$ was the electric flux and we had defined gauss's law in terms of electrostatic flux here we define the magnetic magnetic flux which is $\int b \cdot d a$ now remember we had also shown that $\int b \cdot d a$ is equal to zero if you integrate $b \cdot d a$ over a closed surface you get zero because there are no magnetic monopoles magnetic field lines form closed loops

so $\int b \cdot d a$ over close surface is zero but

so please remember this is not a closed surface this is an open surface

so it could be a surface like this

so for example if this is my ah this is the this is a line this is the uh sorry for example circuit and this could be the surface the surface which is here on the surface

so this could be the surface

so i define $\int b \cdot d a$ as the flux this is the flux

so according to faraday's law changing magnetic flux induces an electromotive force emf you must have studied electromotive force when we were discussing ah circuits

so according to faraday's law any changing magnetic plus flux will induce an electromotive force

so retro the flux is defined as $-\frac{d\phi_b}{dt}$ which is equal to $-\frac{d}{dt} \int v \cdot d a$ this is emf here

so a changing magnetic flux produces an electromotive force that electromotive force is responsible for the generation of current in the circuit you have seen electromotive force because of battery for example earlier a battery has chemical energy inside it this battery has chemical energy that chemical energy is a source of electromotive force and when you current connect a wire outside that electromotive force drives a current through the wire the same current is flowing through the battery

so there is a complete circuit similarly this is another form of electromotive

force and this is because of a changing magnetic flux and electromotive force is defined as integral over a path $\oint \mathbf{e} \cdot d\mathbf{l}$ is the electric field please remember i am calling an electric field not an electrostatic field an electrostatic field for an electrostatic field we know that $\oint \mathbf{e} \cdot d\mathbf{l} = 0$ over closed path zero

so this is an electric field and this $\oint \mathbf{e} \cdot d\mathbf{l}$ induces an emf defined by easy

so this $\oint \mathbf{e} \cdot d\mathbf{l}$ is not electrostatic fields this is an electric field and

so we differentiate the electric and electrostatic field electric fields that electrostatic field generate generated satisfy this condition electric field are not necessarily integral is not zero because there is a force which is driving the current through the circuit

so faraday's law of induction essentially implies that the emf generated is minus of rate of change of magnetic flux this minus comes in because of what is called as lenz's law

so according to lenz's law whenever a change produces an electric current the direction of the current of the induced current is

so as to produce effects opposing the change

so that is contained in this negative sign here if $\frac{d\phi}{dt}$ is positive induced emf is negative if $\frac{d\phi}{dt}$ is negative induced electric field is positive

so this is an important aspect of the induced electromagnetic induced current and that current according to lenz's law is

so as to oppose any change

so if you are for example if this is my coil and if i have a magnetic field passing through this coil what this says is if i change the magnetic flux through this coil by either moving a magnet towards the coil or away from the coil or by placing another circuit nearby whose current is changing or by fixing a magnet and moving this up and down either way whenever the flux through this changes there is an induced current if the flux is increasing with time the induced emf will be such that there is a current generated in this circuit which opposes this change that means it will try to oppose the change in increase of flux similarly if the flux is decreasing with time the induced current will will adjust itself

so that the it opposes any reduction in the flux through this through the circuit now let me rewrite this law here there are there is an important part here which we need to understand

so this law is integral over closed path is equal to minus $\frac{d}{dt}$ of integral dot

so C is the path of integration and S is the surface with C as boundary now again let me try to show you a demonstration to help you to understand what is this what what is the meaning of this

so suppose this was my coil

so let me assume a planar coil

so i can have a coil which which is like this

so if i could have a plane or coil like this

so that's my coil

so i must be careful in choosing the path direction of integration for the path of integration and the corresponding surface and here i must use the right handed rule

so if my path of integration is like this then you see that the right handed screw implies that this surface area must be like this because the right handed screw rotates like this

so if i rotate like this if my path of integration is like this the area must be pointing up if my path of integration is like this the area must be pointing down

so this $d\mathbf{a}$ here is related to the direction in which i am doing this line integral

so if i integrate from here like this you just path closed path starting from here and going like this then because right handed screw implies that this rotation must be towards me area of integration $d\mathbf{a}$ is pointing up if i integrate like this in the other direction from here to this closed path the area is downward

so please keep track of this because that involves the sign here and we must be consistent between the chosen path of integration defined in the circuit c here and the surface s now i must make sure i must make clear that the surface need not be the surface which is flat here all that we need is the surface of integration must have this as the boundary

so the same surface for example for the same path for example i could have a surface which is like this

so i can have the same and this this will be $d\mathbf{a}$ here is $d\mathbf{a}$ the the circuit or the path of integration is only the boundary of the surface

so for example here i could have this flat surface as the surface and this is my path of integration that's a flux or i could have for example the same the same path of integration from here to here but thats my surface

so path of integration is like this but thats my surface i can choose any surface which which is such that this path of integration is the boundary of the surface please remember this is not a closed surface this is an open surface

so this is the path of integration and that's my surface

so if i integrate like this my path of integration the area vector is pointing outward if i integrate like this the area integral here is pointing inward

so there has to be consistency between the path of integration in my line integral here and the surface integration here with $d\mathbf{a}$

so let me show you some examples here

so for example i could have a path like this ah with

so if i do an integration like this the area will be like this and suppose i had a magnetic field in this direction

so that is my area

so here ah

so let me call number one magnetic flux Φ_B is $\int \mathbf{v} \cdot d\mathbf{a}$ is greater than zero because $\mathbf{b} \cdot d\mathbf{a}$ is $b_a \cos \theta$ and $\cos \theta$ is positive

so the flux is greater than zero

so if b increases with time then $d\Phi_B/dt$ is greater than zero

so if the magnetic field is increasing with time the flux is positive and $d\Phi_B/dt$ is greater than zero this implies the induced emf which is $-\frac{d\Phi_B}{dt}$ is less than zero now this area is i am plotting upstairs up upwards here

so the the curve of integration is like this and because b is negative because the induced emf is negative reduced emf must be like this please note here that is my area

so let me look at the coil again yeah

so thats my thats my coil and in this coil i have suppose i do this integration like this the area is pointing up let me assume the magnetic field is pointing like this

so $\mathbf{p} \cdot d\mathbf{a}$ integral is positive if the magnetic field is increasing with time then $d\Phi_B/dt$ is positive which means induced emf is negative

so if i integrate like this i will get a negative value which means that the induced emf must be in this direction which will induce the current flowing in this direction now see in this circuit the current is flowing like this because of induction because the magnetic field is changing with time the flux through

this is changing with time increasing with time actually because it is increasing with time it induces an emf in this direction which induces a current in this direction now what is the direction of the magnetic field produced by this current this current produces a magnetic field opposite to the direction of the magnetic field that you are increasing magnetic field that you applied is in this direction a current like this will produce a magnetic field in the downward direction which is essentially opposing just increase in flux

so please note the current is induced which is trying to oppose the change in the magnetic flux it is not opposing the magnetic field it is opposing the change in the magnetic field it is change it is supposing any change in magnetic flux if you are trying to increase the flux the current is induced such that it tries to decrease the flux if you are decreasing the flux the current induced tries to ensure that the flux does not decrease as fast as you are trying to decrease

so it is a kind of an inertial effect inertia that is happening

so for example let me take another situation

so the same same coil and area is here magnetic field is this is again magnetic flux Φ_B is equal to $\int \mathbf{B} \cdot d\mathbf{A}$ is greater than zero ah if B decreases with time then $d\Phi_B/dt$ is less than zero and induce the emf is greater than zero because that's minus $d\Phi_B/dt$ and because of this area like this this is my path of integration

so emf will be

so the direction of emf now is opposite to the earlier case because the magnetic field is now decreasing with time rather than increasing with time

so let me leave ah two problems for you try to work out what will happen if i have the same areas this is the area A here and magnetic field is downward B increase what is the direction of emf and four the same A B be decreasing with time what is the induced emf direction and this will make you understand that the direction of integration for the line integral for the path of integration relationship between that and the flux and we need to be very careful of using the right signs in these cases also for example if i had a circuit like this let me assume i have a magnet here with magnetic field lines coming like this

so ok this has a magnet ah this is the north pole of the magnet this is output of the bag now if i move the magnet towards this coil now remember ah if i define my areas like this Φ_B $\int \mathbf{B} \cdot d\mathbf{A}$ is greater than zero magnet moving towards coil implies Φ_B increases with time $d\Phi_B/dt$ greater than zero

so emf which is minus $d\Phi_B/dt$ is less than zero

so if this is my path and i define my area here like this and my path of integration should have been this for this integral and this is the less than zero sorry path of integration must be like this the other ground because the area is pointing downward

so the path of integration must be like this

so induced current will be like this when the magnet moves towards the coil towards the circuit here it will induce the current in this direction and as you can work it out that that induced current is trying to oppose the increase in magnetic flux through the coil please work out the remaining situations i leave it as a problem to you what will happen if i had the same coil the same coil here north pole south pole and the magnet is moving like this and if i have south pole north pole magnetic moving like this and then south pole north pole microphone please find the direction of induced currents calcul find out the flux choose a direction of integration path of integration you have a calculation of flux and from there you can find out the direction of induced currents

so please look at this problem very interesting problem to understand and that will make you understand the relationship between the path of integration for the emf and the surface that i must use for the integration and again i must point out the surface need not be the flat surface as long as the path of integration is the boundary of the surface that's fine

so i will stop here and in the next class we will continue with discussion of electromagnetic induction and we will consider some examples and i will show you what kind of fields are entered for currents are induced in circuits thank you very much you